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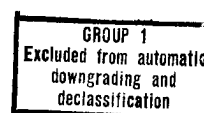
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HEAT TREATMENT OF AIRPLANE PARTS AT MILITARY REPAIR OF AIRCRAFT TECHNIQUE

**Manual
for Specialists of Military Aircraft
Repair Shops of Air Forces**



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AT MILITARY REPAIR OF AIRCRAFT
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Chapter I

Structure and Properties of Metals and Alloys

1. Metals and Alloys

The world surrounding us consists of an enormous amount of various materials. In their turn all these materials are made up of the finest particles - the atoms.

There are all together 110 varieties of atoms. Out of which 88 have been found in nature, and 12 have been artificially created in laboratories. Some materials are composed of only one variety of atoms and such materials are called simple or elements. Other materials consist of several varieties of atoms and such materials are called complex.

Out of known elements in nature nearly 70 are metals (iron, copper, aluminium, nickel, tin, lead, zinc, etc.).

As to their properties metals strongly differ from other elements, non-metals, to which all other elements refer, as for instance phosphorus, sulphur, carbon. Two hundred years ago M.V. Lomonosov was the first one to define metal. He wrote "metals are solid bodies, malleable and bright". This simple definition preserved its meaning up to the present time. We know that all metals have their specific "metallic" shine. Many of them are strong and malleable. Metals are good conductors of heat and electricity. Due to these properties they found wide application in engineering.

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Pure metals are such metals which do not contain admixtures , do not possess high strength and are relatively seldom used . Alloys are mainly used in engineering. Alloys are a complex matter . An alloy may consist of two or several elements. Alloys are obtained as a result of melting of two or several pure metals or metals with other non-metallic elements. For instance, duralumin is obtained as a result of melting of aluminum with copper , magnesium and silicon; bronze-as a result of melting of copper with tin or aluminum ; brass -- as a result of melting of copper with zinc ; while steel is obtained as a result of melting of iron with carbon and with small amount of admixtures of sulphur , phosphorus and other elements.

Sometimes it is sufficient to add to the metal very little of another element in order to change radically the properties of an alloy. Thus , if only 0.2 per cent of carbon is added to pure iron , its strength increases by over two folds as compared with the strength of a pure iron. An alloy of aluminum with 4 per cent of copper and magnesium is 6-8 times stronger than a pure aluminum. An alloy is always stronger than pure metals which are introduced into its composition . An increased strength of alloys has a great practical meaning. The stronger the alloy , the lighter in weight would be the parts , machines , etc. made out of it , which is of a great importance in aircraft building. The Soviet scientists are continuously conducting a search for ever new high-strength alloys.

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All metals and alloys used in engineering are divided into two classes.

First class -- are ferrous metals. Iron and all iron alloys , in which iron makes up the basic part -- pig iron and steels , are referred to this class. The pig iron is an iron alloy containing more than 1.7 per cent of carbon and a small amount of silicon , manganese, sulphur and phosphorus. The carbon content in steel ranges from hundreds of fractions of one per cent up to 1.7 per cent.

When special , the so called alloyed steels and pig irons are manufactured , chromium , nickel , tungsten , molybdenum , vanadium , cobalt , titanium and other metals, in some cases up to 8-6 various metals , are introduced into the alloy. By this way sometimes different steels are obtained which : firstly , possess a very high strength , secondly , possess a high wear-resistance and thirdly , do not break under the action of acids and other chemical elements and also stand high temperature , etc.

Second class-- are non-ferrous metals. They received their name because they possess different colour : copper, for instance , has a light-red colour ; nickel, tin, aluminum - silvery-white ; zinc - light-gray ; lead -bluish-white ; gold - yellow . Alloys of the above mentioned metals are also referred to as non-ferrous metals such as : brasses , bronzes , babbits , etc .

The non-ferrous metals are often divided by their weights into heavy and light metals .

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Heavy non-ferrous metals are metals with a great specific weight . Copper , nickel , chromium, lead, tin, zinc manganese and their alloys are referred to this group of metals .

Light non-ferrous metals , are metals with a little specific weight , such as, for instance , beryllium , magnesium , aluminum , etc . Aluminum received the widest application in the aircraft building. This metal is 3 times lighter than iron and copper ; magnesium is 4.5 times lighter than iron and copper. Lithium is the lightest of metals. It is 1.1 times lighter than iron and almost 3 times lighter than water .

Among the non-ferrous there are rare and precious metals.

Such metals as molybdenum , vanadium , niobium, tungsten are found in small quantities in the earth's crust and therefore they are called rare metals . Although , it is true that the quantity of vanadium and niobium in the crust is much greater than of copper and lead , however they are dissipated in the earth's crust and their extraction from the ores offers the greatest difficulties.

Such metals , which do not oxidize in the open air even at high temperatures and are not destructed by the action of many acids are called precious metals. Platinum , gold , palladium , rhodium and silver are referred to the precious metals. These metals are used for the manufacture of instruments. For example , platinum and rhodium are used for making of thermo-couples.

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2. Structure of Metals

For a long time it has been considered that metal was an amorphous , i.e. , shapeless matter similar to glass , wax and pitch , in which particles - atoms , comprising the matter are disposed irregularly.

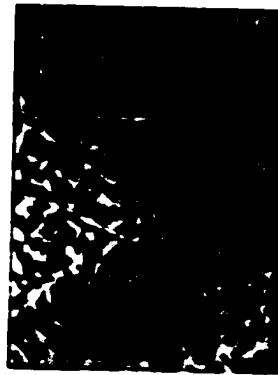


Fig. 1. Grain Structure of Metal .

Now it has been precisely established that every metal comprises a tremendous amount of finest crystalline grains, tightly connected between themselves / Fig.1/ . The formation of crystalline grains takes place in a molten metal at the time of its solidification.

During the cooling of molten metal nuclei of the future crystals are formed at first ; they are the so-called centers of crystallization / Fig. 2,a/. The number of nuclei increases along with lowering of the metal's temperature. / Fig.2b./ The growing crystals begin to press each other, and their regular shape is distorted / Fig.2c/.
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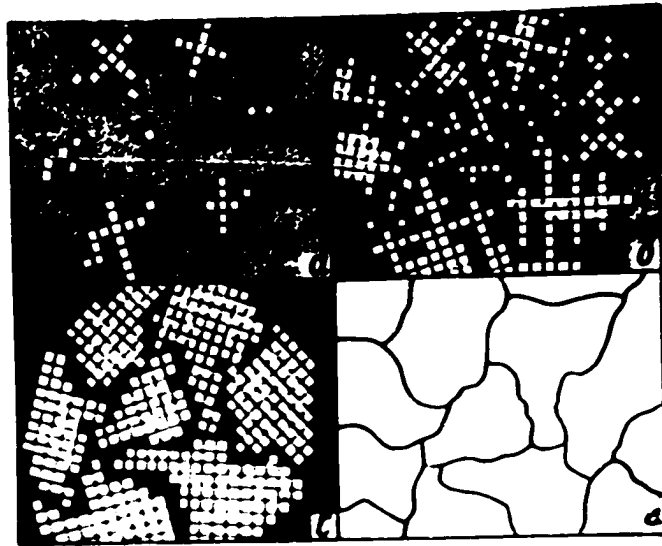


Fig.2. Grains formation in metals:

a/ the nuclei of the future crystals ; b/ the number of nuclei increased , the growth of crystals begins; c/the crystals grow ; d/ the crystals formed grains of metal.

An uneven temperature of different parts of the cooling metal causes the disturbance of crystal's form. Therefore, grains of most different form and size / Fig.2 d/ are observed in the solidified metal . They are divided from each other by separate interlayers -- grain boundaries. The grain size is dependent on the rate of cooling. The quicker is the process of cooling, the finer are the grains. And vice versa , at slow cooling grains of larger size are formed. Besides , the size of the grain is dependent on the number of centers of crystallization. The fewer is their number , the larger are the metal grains.

For study of inner structure , or as it is said , the structure of metal , i.e. the combination of all grains, a microscope is used / Fig.2/. The microscope gives an oppor-

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tunity to examine the metal surface at magnification up to 2000 times.

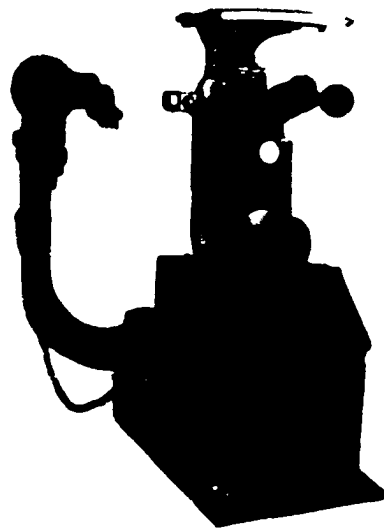


Fig.3. microscope for study of structure of metals and alloys.

Before examination , the surface of metal is cleaned with a file or emery wheel , then it is ground and polished to the mirror finish. Thereupon the surface of the specimen / in polished condition , which is called the micro-section / is etched with acids or other reagents, in order to remove some dirt from the surface and " to expose " the metal by taking off a thin film of oxides. Different grains of metal are etched by acids non-uniformly, and therefore the edges of separate crystals are projected on specimen's surface after etching.

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After etching , the microspecimen is placed under the microscope objective and examination of structure begins. Under illumination of the microspecimen surface by a strong beam of light , a part of metal grains reflect the falling light on them directly into the microscope ocular and under this examination such grains look light. The other grains reflect the light to the side and therefore look dark. Besides , after etching different crystals of metals and particularly of alloys take different colours . This also helps to study the structure of metal or alloy.

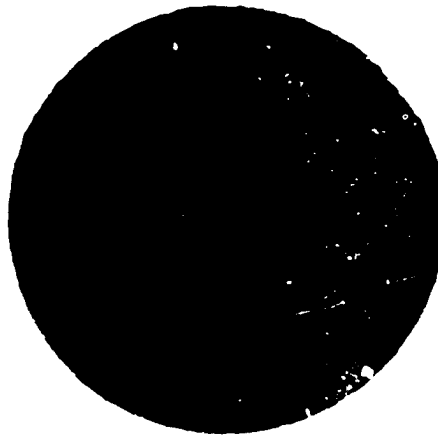


Fig.4. Non-metallic inclusions in metals .
Microspecimen is unetched.
Magnification x 100 .

With the aid of a microscope it is possible to determine the arrangement of separate grains in the alloy, the kind of non-metallic inclusions contained in the alloy / Fig.4/, and whether there were some finest cracks in it / Fig.5/, pores / Fig.6/ , etc.

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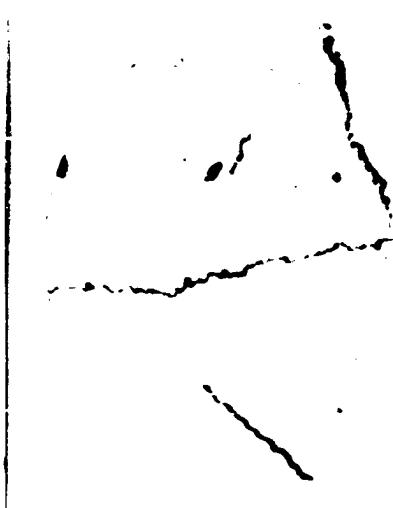


Fig.5. Cracks in metal / magnified 100 diameters/



Fig.6. Pores in metal

What is crystal, how a separate grain of metal is formed?

Crystal is a hard body possessing strictly definite geometrical form. Atoms of metal are arranged in a crystal in a strictly definite order and form, one or another space lattice. / Fig.7/



Fig.7. Types of crystalline space lattice:
a/ body-centered cubic lattice ; b/ face-centered cubic lattice ; c/ close-packed hexagonal space lattice.

It is not possible to find out the arrangement of atoms in the space lattice under any microscope. The structure of the space lattice is studied with the aid of X-rays and radiograms, i.e. pictures, which are made by X-rays after their reflection from different crystals planes on the photographic plate.

The X-ray investigations have shown that three types of space lattices are often met among the metals:

a/ body-centered cubic lattice - atoms in this lattice are arranged in the corners of the cube and in the center of the cubic cell / Fig. 7, a/: iron, chromium, vanadium and tungsten possess this space lattice;

f/ face-centered cubic lattice - atoms in this lattice are arranged in the corners of the cube and in the centers of the cubic faces / Fig. 7, b/: for example aluminum, copper, lead, gold and iron at the temperature above 910°C possess this space lattice.

c/ close-packed hexagonal space lattice in which, besides the atoms arranged in the corners of the hexagonal prism, there are three more atoms inside of the hexagonal prism volume / Fig. 7, c/: this space lattice can be found in the crystals of magnesium, zinc and beryllium.

Many properties of metal are dependent on the type of space lattice. That is why it is important to know the arrangement of atoms in the crystal of metal.

It has been proved that the space lattice of one and the same metal may be changed for instance from the body-centered lattice to the face-centered lattice, if the conditions are changed, i.e. the metal is heated. When the space lattice is rebuilt the crystal structure of metals is changed too.

The property of some metals to rebuild the crystal lattice with the temperature change, i.e. to form the crystals of different shapes, is called the allotropy / it is translated from the Greek word -- allotropy which means "another turn" or "another property". The properties of metals are sharply changed when allotropic transformations take place: thus specific weight / and consequently the volume /, strength, plasticity, etc. become different.

The allotropic transformations permit to change essentially at our will the properties of one and the same steel by its heating with subsequent cooling, i.e. by way of heat treatment.

It may be said that all heat treatment of steel is based on the properties of steel to change its crystal space lattice when it is heated to the temperature of $720-910^{\circ}\text{C}$ with a subsequent cooling.

Let us consider the allotropic transformation of pure iron.

At room temperature, the pure iron possesses a body-centered cubic lattice α -iron / see Fig. 7, a/. If the iron is heated to the temperature of 910°C rebuilding of space lattice into face-centered cubic lattice takes place / see Fig. 7 b/.

This modification is called γ -iron. On the contrary, on cooling from the above mentioned temperature a reverse rebuilding of atoms in the crystal space lattice takes place : δ -iron transforms into α -iron.

Interesting is the fact that at rapid cooling of iron / and particularly of steel /, the rebuilding of space lattice is retarded and concludes at still lower temperature than at the time of slow cooling.

At a rather rapid cooling from a higher temperature in many steels a crystal space lattice may be observed, which is distinctive of steel at high temperature . Here we come close to the explanation of physical nature of hardening , which will be discussed further on.

3. The Constitution of Alloys

An alloy is a crystalline matter consisting of atoms of two or several elements.

The alloy , as was already mentioned above, is obtained usually by fusing together of metals or by alloying of a metal and nonmetal. Molten metals usually dissolve well in each other and form a uniform liquid solution. The properties of an alloy depend both on the properties of the metals themselves forming the alloy and on their percentage in the alloy. For instance , when studying the alloys of aluminum with copper , a sharp difference in the properties of alloys containing 5% and 10% of copper may be found. The second alloy will be harder and more brittle than the first one. Steel , containing 0.2 per cent of carbon possesses lesser strength than the steel , containing 0.4 per cent of carbon.

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However , the properties of an alloy are dependent not only on its chemical composition , but also in its inner constitution and structure . At present time, therefore , a great attention is being paid to the study of inner structure of the alloys.

The constitution of different alloys is dissimilar. The component parts of an alloy may form with each other either a mechanical mixture , or a chemical compound , or even a solid solution.

An alloy , in which each metal is found in the form of separate grains , is called the mechanical mixture . The grains do not interact with each other chemically , but are present in the mixture in an isolated condition . Aluminum with silicon and copper / Fig. 8/ , lead with antimony , cadmium with bismuth and others may form the mechanical mixtures.

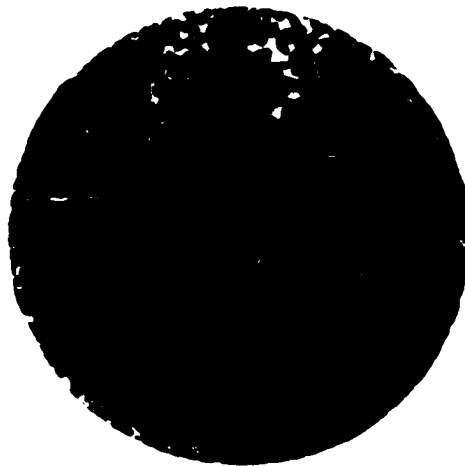


Fig.8. Microstructure of mechanical mixture of two metals.

An alloy, composed of mechanical mixture of metals, has always only one and definite composition, possessing the lowest melting temperature. The alloy with such composition is called an eutectic alloy, or simply eutectic, which means readily fusible. The metals, which at melting form the eutectic are always fused at the lowest temperature for the given alloy. When one of the metals found in the alloy is in a quantity greater than it is necessary to form the eutectic, then it is fused at a higher temperature. The eutectic alloys of aluminum with silicon -- siluminas and alloys nearest in their composition to the eutectic, find their wide application in aircraft building.

Sometimes at fusing, separate parts of an alloy unite with each other in certain weight proportions multiple to their atomic weights and form crystals of chemical compound with a definite crystal line space lattice. Thus for instance vanadium in steel unites with carbon and forms a new compound -- vanadium carbide. Crystals of chemical compounds are present in the alloy structure independently. However, alloys consisting of similar chemical compounds do not exist.

Often chemical compounds possess great hardness and brittleness. Of particularly high hardness are the carbides of such metals as tungsten, niobium, titanium, vanadium, chromium, molybdenum. These carbides are always present in the structure of hard alloys and high speed steels. / Fig. 9'.

Let us acquaint ourselves with one of the widely known alloy structures -- solid solution. Solid solution is a crystalline component of an alloy in which atoms of a dissolved metal either replace the atoms of the metal solvent in the crystal space lattice, or dispose among them.

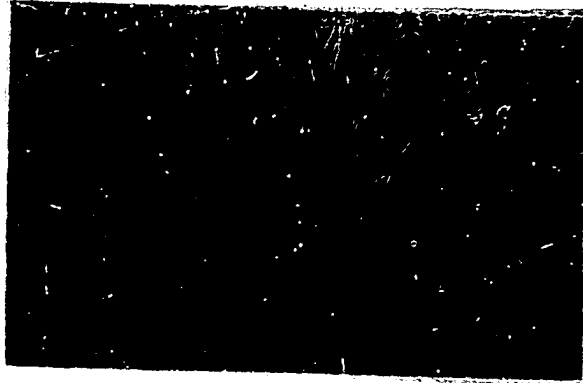


Fig.9. Microstructure of high speed steel containing hard carbides.

As we said above , many metals in molten condition dissolve well in each other. At cooling of an alloy , the atoms of molten metal are left mixed with atoms of metal-solvent. A solid solution is formed at cooling of this alloy. Many metals possess an ability to form solid solution , as for example , aluminum forms solid solutions with copper , magnesium ; iron -- with carbon , manganese, chromium , nickel and other elements ; copper -- with nickel . Any amount of nickel can be dissolved in copper and vice versa. However not all metals possess such limitless solubility . Majority of metals dissolve in each other in limited quantities.

In a solid solution the atoms of dissolved metal are "mixed" with atoms of the metal-solvent. How the crystals of solid solution are built.

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An X-ray examination of solid solutions has shown that they were built differently. Their structure is dependent on the arrangement of atoms of dissolving metal in the crystal space lattice of the metal-solvent.

If the solid solution contains metals whose atoms in their size differ insignificantly from each other / their diameters differ by not/^{more}than 15 per cent/ , then the atoms of the molten metal may replace the atoms of the metal-solvent at any place of the crystal space lattice / Fig. 10, a/. Such alloys are called solid solutions of substitution . The solid solutions of substitution type form alloys of iron with nickel , manganese , chromium .

In a case when diameters of atoms of two metals differ from each other by more than 15 per cent / at this , the diameter of atoms of the metal solvent is greater than the diameter of atoms of the molten metal /, then at their fusing , atoms of metal with small diameter are embedded between atoms of the metal with greater diameter .

Such alloys are called solid solutions of interstitial type / Fig . 10, b /.

Steel can serve as an example of such alloys . Steel is an alloy of iron and carbon. The carbon atoms are of considerably smaller diameter than the iron atoms , and therefore they are embeded in the crystal space lattice of iron and settling between the iron atoms extend the lattice, thus distorting it. The distorted crystal lattice of steel, tightly packed with carbon atoms , is more difficult to be destroyed at deformation , than the lattice of pure iron

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without such filling of empty space between the atoms. That is why the alloys are always stronger than the pure metals of which the alloy is composed of.

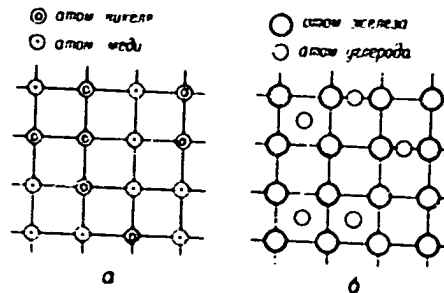


Fig. 10. Arrangement of atoms :

a/ in solid solution of substitution type , b/ in solid solution of interstitial type.

1/ atom of nickel ; 2/ atom of copper; 3/ atom of iron ; 4/ atom of carbon.

4. Basic Elements of Steel Structure

The solid solution of carbon in a pure α -iron possessing body centered cubic-lattice is called ferrite. The structure of pure iron consisting of ferrite grains is shown in Fig. 11.

The soft steels having a ferrite structure are easily stamped , welded and forged.

The chemical compound of iron with carbon -- iron carbide Fe_3C is called cementite.

The cementite is distributed in the steel in the form of a network along the grain boundaries , in the form of needles and fine grits, dessemminated over all grains and on their boundaries.

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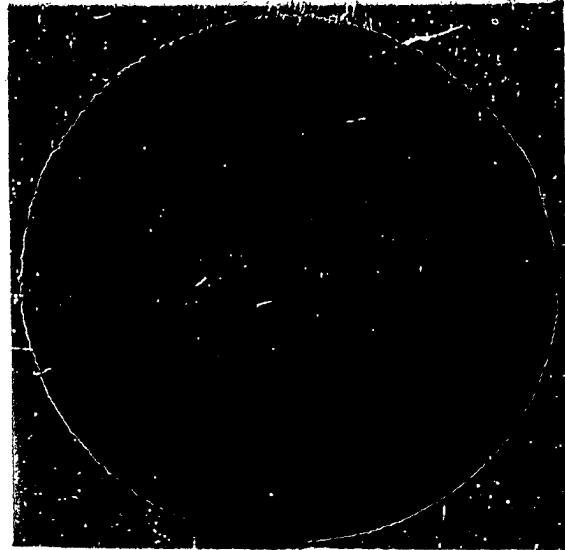


Fig.11. The microstructure of pure α --iron /ferrite/.
Magnified 100 diameters.

The cementite possessing high hardness , is brittle and cannot be subjected to forging.

The solid solution of carbon in γ -iron is called austenite. γ -iron possesses face-centered cubic lattice. The carbon atoms are disposed in the austenite in the center of the cube. The austenite structure is composed of characteristic uniform bright grains / Fig.12/ . In pure alloys of iron with carbon , and in regular carbon steels, austenite is stable at high temperatures only. In steels with high content of special elements / alloyed steels /-- chromium , nickel , manganese and others -- austenite is stable even at room temperatures.

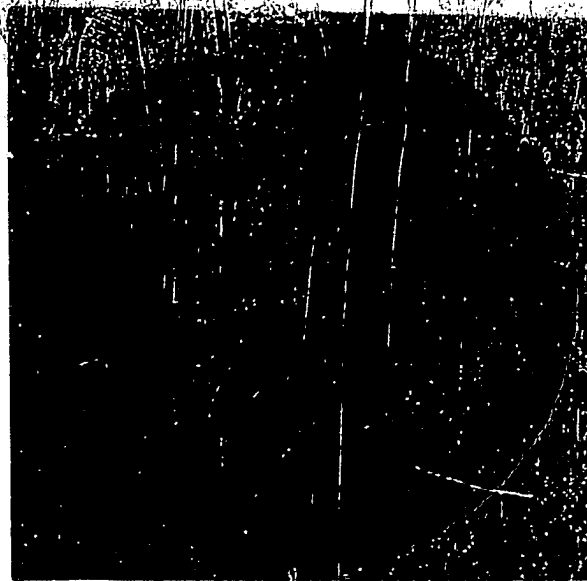


Fig.12. The microstructure of γ -iron /austenite /
Magnified 100 diameters

The austenite steel resists very well wearing. It is quite plastic and steady against the action of acids. Stainless steels have usually the austenitic structure.

Steel containing 0.83 per cent of carbon consists of pearlite.

A mixture of fine grains of ferrite and cementite is called pearlite. This structure was called so on account that the cementite lamellae reflects the light like the mother of pearl .

In each pearlite grain , parts of ferrite and particles , which form the grain , are arranged in the structure as alternated between themselves lamellae. Therefore such pearlite is called lamellar pearlite / Fig. 13, a and b /.

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Besides the lamellar pearlite , high carbon steel , after special heat treatment , may contain globular pearlite.

The physical properties of pearlite depend on the degree of its desintegration . Steel containing in its structure pearlite with fine lamellae of cementite possesses the strength one and a half times higher , than the steel with coarse grained pearlite .

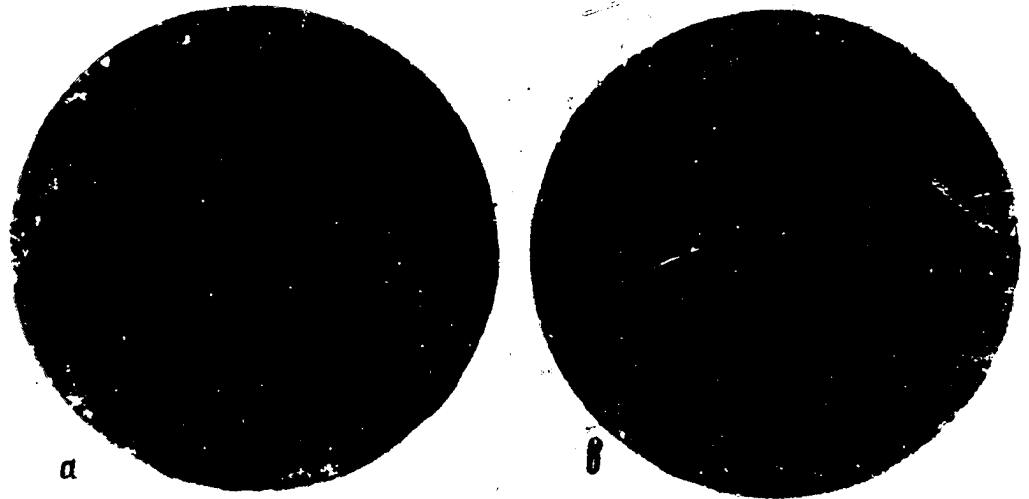


Fig. 13. Microstructure of lamellar pearlite
a/ Magnified 400 diameters ; b/ Magnified 2000 diameters.

When the carbon content in steel is near zero , the structure of steel consists of ferrite grains only; in steel structure with carbon content from 0.14 per cent, besides the large quantity of bright ferrite grains, small gray parts of pearlite are observed . With further increase of carbon content from 0.1 per cent up to 0.83 per cent, the number of bright ferrite grains becomes lesser and

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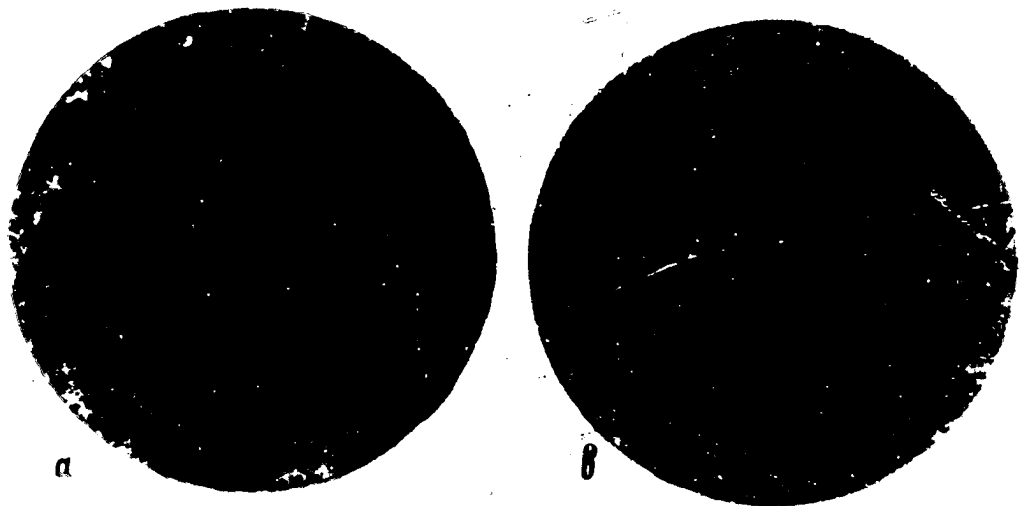


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lesser / Fig. 14/. Steel containing 0.83 per cent of carbon consists of pearlite only.

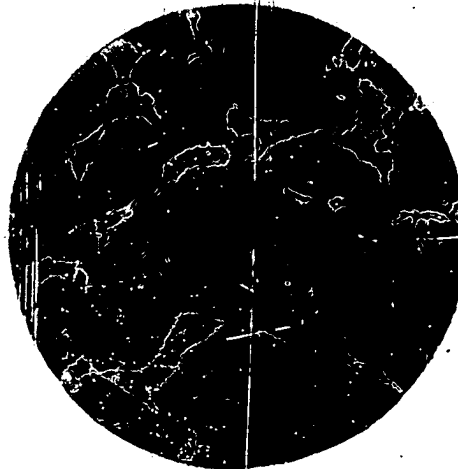


Fig. 14. Microstructure of annealed steel/bright grains-ferrite ; gray --pearlite /.
Magnified 200 diameters.

When the carbon content in steel exceeds 0.83 per cent besides pearlite this steel may also contain some cementite

5. Defects in the Structure of Steel

Properties of steel depend to a great degree on its structure . The coarse grained structure resulting from over-heating of steel / Fig. 15/ decreases the strength of steel , particularly under the action of impact loads. If the structural components -- the grains of ferrite and pearlite , are located in the metal in the form of streaks, then the so called streaky structure is formed . The streaky structure / Fig. 16/ creates non-uniform mechanical properties of steel in direction of longitudinal and transverse rolling of steel.

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Fig.15. Microstructure of overheated steel/white parts -ferrite; gray - pearlite/ Magnified 200 diameters.

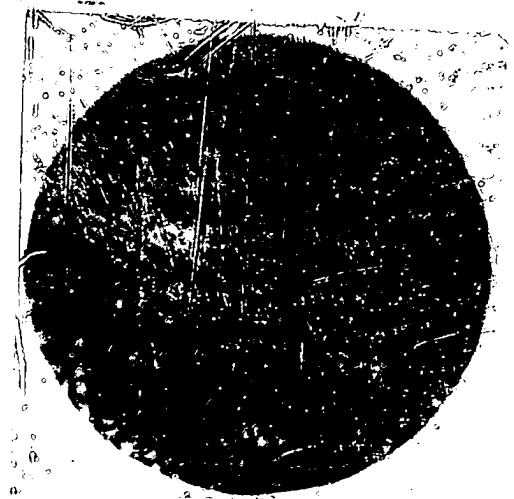


Fig.16 . Streaky location of ferrite and pearlite in steel. Magnified 200 diameters.

This structure worsens the technological properties of steel, when treating by cutting and cold stamping .

At a faulty heat treatment of steel parts , burning out of carbon in the upper layer of steel takes place / the so called decarburization , Fig. 17/ , which disturbs the uniform structure of steel and lowers its strength .

Non-metallic inclusions in metal are very detrimental to the steel structure / See Fig. 4/. They disturb the uniformity of metal , lower its strength and also cause the concentration of stresses . Such concentration of stresses is especially dangerous when the part works under the action of alternating and impact loads . Besides , at a rapid cooling of heated steel the non-metallic inclusions in steel may cause cracks .

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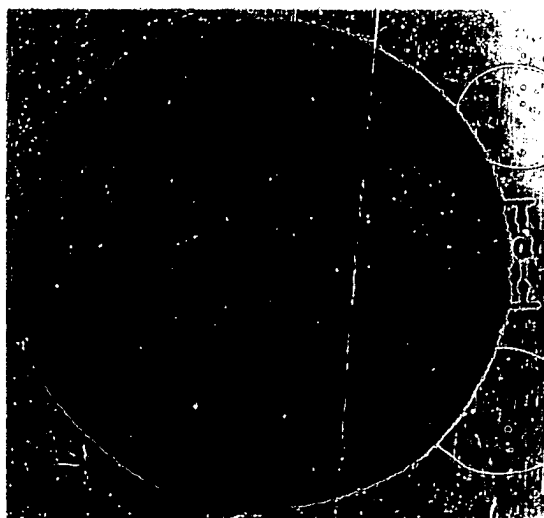


Fig.17. Microstructure of decarburized steel surface
a) - decarburized layer. Magnified 100 diameters

6. Influence of Chemical Elements .

Included in the Composition of Steel

Besides iron and carbon , the steel is composed of many other elements which differently influence upon the properties of steel. Some of them as admixtures are inevitably present in the steel as for example : silicon, manganese , sulphur and phosphorus ; others are added to steel as alloying elements .

C a r b o n is a basic element , which determines the mechanical and technological properties of steel and its responsiveness to heat treatment . The more carbon there is in steel , the stronger and harder it is , but at the same time the steel becomes less plastic and more brittle. The increase of carbon content in steel improves its responsiveness to hardening . Steels containing less than 0.2 per cent of carbon practically do not harden . The amount of carbon is strictly limited in all grades of steel.

Manganese is a very useful component of steel . The manganese content in carbon steels varies from 0.25 to 0.70 per cent. In such amounts the manganese has little effect on the steel properties and therefore is considered as an admixture . When manganese content in steel is 0.8 per cent and over it already becomes an alloying element. For instance , steel grade 80 x 7CA / chromansil/ contains from 0.8 to 1.1 per cent of manganese ; manganese with iron forms a solid solution thus strengthening the iron . As we shall see further on , the manganese eases the heat treating of steel parts of large dimensions , or as it is said , increases the hardenability of steel . Manganese combines the

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harmful admixture -- sulphur and transforms it into harmless chemical compound -- sulphide of manganese ; besides , the manganese purifies the steel from the harmful admixture of oxygen , i.e. deoxidizes steel at its casting .

S i l i c o n is introduced into molten steel as a deoxidizer . The greatest part of silicon combined with oxygen of steel goes into slag. The amount of silicon left in steel is from 0.15 up to 0.37 per cent. As in the case with manganese , silicon in this percentage is considered as an admixture in steel. When the silicon content in steel increases more than 0.5 per cent , it becomes an alloying element . Steel grade 30 x CA contains silicon within the limits from 0.9 to 1.2 per cent , and even in this small quantity it increases its strength , hardness and elasticity .

Sulphur is a harmful admixture in steel ; it comes into steel from an iron ore. Sulphur and its compounds with iron, are found at the grain boundaries of the steel . At heating of steel to the temperature of 1000-1200°C for forging and rolling , the compounds of sulphur with iron are melted at lower temperature / 985°C/ and in the heated steel they remain in a liquid state. During forging and rolling of steel this liquid , being incompressible , breaks the base metal , thus forming tears , both inside and outside of the metal . This phenomenon is called hot shortness. That is why measures are taken to remove the sulphur by combining it with manganese . The maximum allowable content of sulphur in high grade steel must not exceed 0.030 - 0.035 per cent.

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Phosphorus, like sulphur, comes into steel from iron ores. It is also harmful since it is soluble in the ferrite which causes its brittleness at regular temperatures. This phenomenon is called cold shortness. The phosphorus content in the aircraft grades of steel is usually allowed not to exceed 0.035 per cent.

Steels containing, in addition to the above mentioned elements, even one of such elements as nickel, chromium, molybdenum, vanadium, titanium or others, or increased content of manganese / over 0.8 per cent / or silicon / over 0.5 per cent / are called alloyed steels.

The alloyed steels, besides high strength and plasticity, possess some other valuable properties; they have high resistance to corrosion, good resistance to wear at friction and high degree of hardenability.

Let us consider the influence of some alloying elements on the steel properties.

N i c k e l dissolves in steel and rises its strength and toughness at impact loads and facilitates the heat treatment. The aircraft alloyed steels contain up to 5 per cent of nickel.

C h r o m i u m in a quantity from 0.5 to 20 per cent is widely used for alloying of steel. It not only dissolves in ferrite but also forms strong chromium carbides which increase the wear resistance of chromium steel. Chromium appreciably increases resistance of steel to corrosion and oxidation at heating.

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Nickel and chromium together make it possible , at alloying , excellently to utilize the positive influence of both elements . Chromium imparts hardness while nickel imparts toughness to chromium-nickel steels. At a greater content of chromium and nickel , steel acquires rather valuable properties -- heat and scale resistance - capability to withstand high temperatures and loads .

V a n a d i u m is the most important addition to steel . It is enough to add 0.1-1.2 per cent of vanadium to make the steel fine grained , hard and also to form stable carbides .

M o l y b d e n u m and t u n g s t e n combining with carbon also form carbides. Besides , a part of molybdenum and tungsten dissolve in the ferrite . These elements rise appreciably the strength of steel at its working in conditions of high temperatures . Molybdenum and tungsten are added to steel in small quantities / up to 0.2 - 0.3 per cent /. High Speed tool steels may contain tungsten up to 10 per cent.

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Chapter II

Physical Properties of Metals and Alloys

1. Conception of Loads

When selecting the metal for the manufacture of parts it is important to know its strength, i.e. its ability to withstand loads, which the part must resist during operation.

As to the character of loads, acted upon working parts they are known as static loads, i.e. loads acting permanently or changing slowly their value, and dynamic loads, i.e. loads changing rapidly their value. Stresses, arising in the parts of aircraft chassis standing on a landing field resulting from the airplane's weight, can serve as an example of static load. At the time of airplane landing the same parts are subjected to the action of the impact dynamic loads.

A great number of airplane and engine parts are also subjected to the action of periodical and alternating loads.

Periodical loads are such loads, when the applied force periodically changes their value, either increasing or decreasing.

Alternating loads are such loads, which change in a short space of time not only their value, but also their direction / for example loads causing bending either to one, or to another side/.

It is always necessary to bear in mind not only the absolute value of the load, but also the character of its action upon the part. The fact is that the ability of the

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material to resist periodical and alternating loads at ordinary temperatures is considerably lower, than to resist static loads. If we take three similar parts and apply static load to the first part, periodical -- to the second, and alternating load to the third one, and if at this the first part withstands 100 kg., then the second -- only 66 kg, while the third -- merely 33 kg.

2. Deformation of Metal

The outside forces acting upon the part are tending to

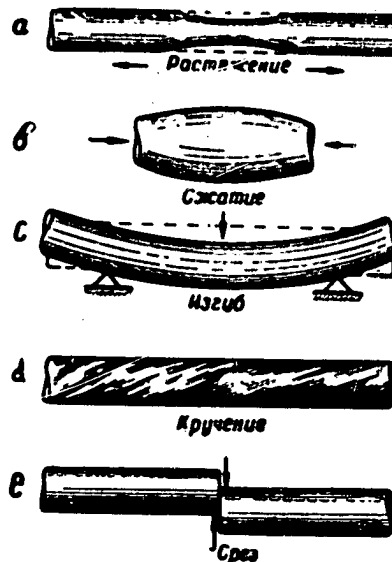


Fig. 18. Various kinds of metal deformation :
a/ Tension; b/ Compression ; c / Bending; d/ Torsion ;
e/ Shearing .

deform it, while the forces arising inside the part among separate crystals are tending to resist deformation. These forces are known as crystalline forces or forces of elasticity. As a result of simultaneous action of outside deforming stresses upon the part and the opposing crystalline forces, strains arise in the material.

There are five basic types of deformation : tension , compression , bending , torsion and shearing. Let us consider certain types of deformation and define the character of strains resulting these deformations in metal.

/ Fig.18/.

T e n s i o n / Fig . 18 , a / . Tension deformation appears in those cases , when the applied forces are directed along the parts axis and tend to pull it apart . Elongating under the action of the pulling forces the part contracts , i.e. its cross-sectional area reduces. Crankcase cylinder fostering pins and others can serve as examples of parts sustaining tension . The forces resisting pulling deformation cause strains in the pulled asunder parts. These strains are distributed uniformly over the whole area of the part's cross section .

The numerical meaning of the strain is determined by the stress acting upon each unit of the cross sectional area. If the force applied to the testing part is denoted by letter P, the cross sectional area by letter F, and the value of tension by letter σ / sigma /, then the following formula can be written :

$$\sigma = \frac{P}{F}$$

The force P is measured in kilograms and the cross sectional area in square centimeters or square millimeters . If the diameter of the part is 10 mm, and the cross sectional area is $F = 78,5 \text{ mm}^2$, then the applied force P equaling , for example 1000 kg. causes strain in the material of the part.

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$$\sigma = \frac{F}{F} = \frac{1000}{78.5} = 12.7 \text{ kg/mm}^2$$

C o m p r e s s i o n / Fig. 18, b / . At compression the outside forces act along the part's axis , and they are directed against the pulling forces. As a result of action of these forces , the longitudinal dimensions of the part are decreased and transverse dimensions are increased. Washers , gaskets in flange connections and many parts of chassis are subjected to compression . If the length of the compressed part is 10 times larger than its transverse dimensions , then additional stresses appear and the part is subjected to bending .

B e n d i n g / Fig. 18 , c / . Bending is a deformation, which causes bending of a part under the action of applied forces. The bending deformation appears in the part when it is placed on one or several supports and the force acts perpendicularly to the part's axis.

At bending some layers of the part are pulled and others compressed . Longerons of an airplane wing are subjected to the bending deformation .

T o r s i o n / Fig. 18, d / . In those cases when some fibers of the part or the whole part itself is twisted around longitudinal axis , then the torsional deformation takes place. It may appear in different revolving parts of the machine / shafts / and in tools / drills, screw-drivers , etc./ . At twisting of the part , the points of cross section situated further from the part axis , shift over a greater value than the points of the section situated near the lon-

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gitudinal axis. That is why deformation and strains of twisting grow as they shift further away from the axis of the part. This enables to utilize hollow shafts in which the less loaded inner part of the shaft is removed.

S h e a r i n g. Deformation at shearing / shearing stress / is observed in the case when two forces , equal in their value , act perpendicularly to the longitudinal axis of the part at a very close distance from each other and are directed towards each other. In this case some of the layers of metal displace in relation to others. If at this deformation the wholeness of the rod is broken , then the shearing takes place / Fig.18,e/. The swing bolts of airplane control traction can serve as an example of the parts sustaining the shearing deformation .

It is necessary to take into consideration that the parts of the airplane and the engine are subjected simultaneously to several kinds of loads and sustain complex deformation . For instance , blades of a gas turbine of a jet engine sustain simultaneously tension , bending and torsion ; the turbine shaft is subjected both to twisting and tension .

3. Physical properties of metals

Strength , elasticity , plasticity , hardness , resistance to wear , toughness as well as endurance and conditions of operation under periodical loads are known as physical properties of metal.

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S t r e n g t h is the ability of metal to resist breaking under the action of external forces / for example , resistance to the action of pulling forces /.

E l a s t i c i t y , is the ability of metal to regain its original shape after the forces causing the deformation stop acting upon it . Steel spring , which instantly regains its shape when forces stop to act upon it , can serve as an example of the elastic part .

P l a s t i c i t y , is the ability of metal to change its shape under the action of external forces without breaking , or to regain its shape after the forces stop acting upon it.

H a r d n e s s , is the resistance which the metal exerts to indentation of other harder body into it.

R e s i s t a n c e t o w e a r , is the ability of metal to maintain dimensions and original state of the surface of two and more articulated parts of the unit at their prolonged shifting at conditions of tight mutual contact .

T o u g h n e s s , is the ability of metal to sustain the impact loads. Brittleness is the opposite property of metal . A brittle metal breaks at an impact comparatively easily ; on the contrary tough metal can sustain shocks without breaking . The impact ductility is a very important characteristic of metal . It is determined by the amount of work in kilogram-metres / kgm/ necessary to break a special specimen in time of its impact bending .

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If the amount of necessary work is related to the cross sectional area / in cm^2 / of the test specimen at the point of its breaking , then we obtain specific impact ductility. It is expressed in kilogram-metres per square centimetre / kgm/cm^2 and is denoted as a_H .

Endurance is the ability of metal to sustain repeatedly recurrent periodic loads which change both its value and its sign / for instance alternating tension and compression , alternating bending in opposite sides , etc./

Tensile test of metal

The tensile test of metal gives the opportunity to determine elasticity , strength and partly toughness of metal. The specimen of the tested metal is prepared as a rod with thickening at its ends which are inserted into the grips of the testing machine. The testing machine is supplied with a dynamometer -- a device for measuring of the pulling stress. Besides , the machine has a device which plots the curve of dependance between the load and elongation of the test specimen . This curve is called the tension test diagram . / Fig.19/.

The straight line up to the point A shows that elongation of the specimen grows proportionally to the increasing of load. The stretching deformation of the specimen at this part of the diagram is elastic , i.e. , the specimen regains its original length when the loads had been taken away.

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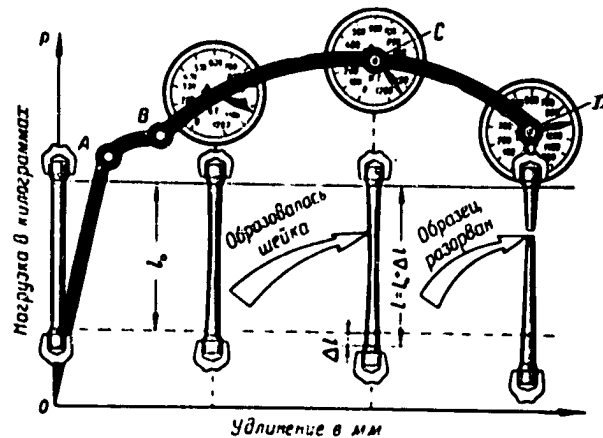


Fig. 19) Tension test diagram :

1/ Elongation in mm; 2/ Load in kilograms;
3/ Formation of the neck ; 4 / The specimen being broken .

When the load increases above the point A up to the point B and then is taken away , the specimen does not regain its original length. This is evident of the permanent deformation of elongation . A part of the tension diagram A B C D characterizes the range of plastic , irreversible deformation . As the stretching progresses further , a neck is formed on the test specimen at the point C and the deformation of material takes place without an increase of the load. At the point D the test specimen is broken.

The purpose of the tension test of the metal is to determine the ultimate strength of the material .

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The ultimate strength σ_B of the metal is the value of breaking strength in kilograms per each square millimetre of the original area of the test specimen cross section .

$$\sigma_B = \frac{P_{\max}}{F}$$

where F is the cross sectional area of the test specimen in mm^2 .

Example. To determine the ultimate strength of the specimen 10 mm in diameter which was broken at the load of $P = 3000$ kg.

The specimen is 10 mm in diameter and its cross sectional area is

$$F = \frac{\pi d^2}{4} = \frac{3.14 \cdot 10^2}{4} = 78.5 \text{ mm}^2$$

Then the ultimate strength will be

$$\sigma_B = \frac{P_{\max.}}{F} = \frac{3000}{78.5} = 38.2 \text{ kg/mm}^2$$

The relative elongation of metal is determined simultaneously with ultimate strength at the testing for tension .

If the test specimen too long is pulled then it is stretched by the value

$$\Delta l = l - l_0,$$

where l - specimen length after rupture .

The relation of the length increment Δl to the original length expressed in per cent is called relative elongation and is denoted by letter δ /delta/:

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$$S = \frac{\Delta l}{l_0} = \frac{1 - 10}{10} \cdot 100 \%$$

Example . To determine the relative elongation ,
when the original length of the test specimen
 $l_0 = 100$ mm while the increment of length
 $\Delta l = 2$ mm.

The elongation will be:

$$S = \frac{\Delta l \cdot 100\%}{l_0} = \frac{2}{100} \cdot 100\% = 2\%$$

The relative elongation determines the ability of metal to stretch , however , the toughness of metal , to a certain extent , may be defined according to the value of the relative elongation . As a rule , brittle metals possess insignificant relative elongation .

Determination of the Hardness of Metals.

Hardness is a very important property of metal. As already has been mentioned before , hardness is the resistance which the metal exerts to indentation of other harder body into it. Hardness of different metals and alloys varies greatly. In steels the hardness is dependent on the carbon content and the method of heat treatment. Therefore the test for hardness is carried out after each heat treatment .

The most widespread methods of hardness determination are based on the principle of indentation into the tested metal of such hard bodies as diamond or hardened

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steel ball. A steel ball of strictly specified size is indented with a predetermined load into the tested metal, after which the diameter of the obtained impression of the metal surface is measured. / Fig. 20/. The relation of the load value with which the steel ball is indented into the metal to the value of surface impression serves as an indicator of hardness. Hardness is denoted by letter H_B kg/mm^2 / the so-called Brinell hardness number /.

Determination of hardness with Brinell tester is usually accomplished with a steel ball 10 mm in diameter, and the load $P = 3000$ kg. When the tested metal hardness is near to the hardness of the hardened steel, then a diamond cone is used for determination of its hardness. It is also indented into the surface of the metal, and at this a special device - hardness-tester TK-1 / Rockwell hardness tester, Fig. 21 / - records the depth of the impression and automatically records the hardness in conventional units - HRC.

When hardness is determined under a load of 60 kg then the reading of hardness in conventional units is performed on scale A. In this case hardness is denoted by the letter HRA. When hardness is determined under a load of 150 kg., the reading of hardness is performed on scale C. In this case hardness is denoted by the letter HRC.

Besides the diamond cone, the Rockwell device is furnished with a hardened steel ball of 1/16 inch in diameter, which is used for testing of metal hardness. In this test, the hardness is expressed in conventional units. The reading

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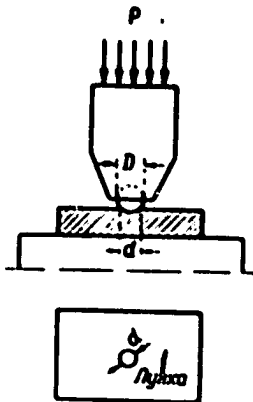


Fig.20. Chart of Brinell hardness testing of metal.
1. Indentation .

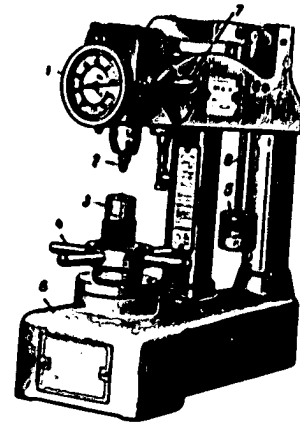


Fig.21. Device TK-1 for determination of hardness.
1. Indicator; 2. Diamond or a steel ball ; 3. Object stage with a screw; 4. Handle; 5. Load ; 6. Housing; 7. Handle ; 8. Rod.

of hardness under the load of 60 kg on a steel ball, is performed on the scale F-HRP , and under the load of 100 kg. on the scale B / the hardness is denoted HRB/.

The determination of hardness of machine parts , using the hardness-tester TK-1 / the Rockwell device/ , is performed in the following succession ;

1. The diamond cone or steel ball tip 2 is set into the device and the load 5 is put on the rod 8.
2. The place on the part to be tested is cleaned with an emery cloth for hardness determination .
3. The part is set on the object stage 3 in such a way as the tested surface be perpendicular to the vertical axis of the diamond cone.

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4. The object stage 3 with the aid of the handle 4 is lifted until the tested part comes into contact with a diamond cone. Thereupon, carefully raising the object stage by rotation of the handle it is necessary to take care that the small hand of the indicator 1 stops against the red point and the large hand stops in the vertical position with allowable deviation $\pm$ 5 divisions.

5. By rotation of the indicator ring to the large hand, a zero of the black scale is set.

6. The handle 7 is carefully shifted to the support and it is necessary to wait 5-10 seconds allowing the diamond cone to penetrate the surface of the tested part.

7. After 5-10 seconds the handle 7 is again set into original position.

8. The hardness value is read as indicated by the hand on the scale.

On determining the hardness value of metal, it is possible to say in advance how easy it would be machined on the lathe by cutting. The harder the metal, the more difficult its machining. On the other hand, harder steels and alloys better resist wear. Parts made of hard metals will serve longer without wearing.

By hardness of metal it is possible to judge whether the heat treatment of steel was carried out properly. That is why in the assignments for heat treatment, the hardness which the steel must possess after heat treatment, should be indicated.

Besides, it has been established that certain relation exists between the tensile strength and the hardness

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of metals . The harder the metal , the greater is its strength.

The tensile strength constitutes approximately one third of the hardness value measured at the indentation of the steel ball into the metal surface . Knowing the hardness of metal and using the interdependence between the hardness of metal and its strength , it is possible to determine the tensile strength avoiding the cumbersome tests of specimens for tension .

The following formulae of conversion are used to determine the tensile strength according to the known number of hardness :

For carbon steels $\sigma_B = 0.36 \text{ HB}$;

For chromium-nickel steels $\sigma_B = 0.35 \text{ HB}$;

For cast aluminum $\sigma_B = 0.26 \text{ HB}$;

For bronze and brass / annealed / $\sigma_B = 0.55 \text{ HB}$;

For bronze and brass / hardened / $\sigma_B = 0.40 \text{ HB}$.

By utilizing tables given at the end of this book it is possible to find quickly the strength of the steel according to the known value of hardness.

For instance , at testing of steel specimen made of chromium-nickel steel the hardness value $\text{HRC} = 38$ was obtained . What is the tensile strength of this steel ? We find on the table that the chromium-nickel steel with hardness $\text{HRC} = 38$ possesses tensile strength of 180 kg/mm^2 . According to the above mentioned formula the tensile strength would equal to

$$\sigma_B = 0.36 \text{ HB} = 0.36 \cdot 350 = 126 \text{ kg/mm}^2$$

The difference is very insignificant .

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Chapter III

CLASSIFICATION AND MARKING OF STEELS

As to its chemical composition, the steels are subdivided into two groups: commercial quality / carbon/ and high quality / alloyed / steels.

1. Carbon steels

Carbon steels -- are alloys of iron with carbon. The carbon content in steel may vary within the limits from hundredth fraction of one per cent up to 1.4 per cent. Carbon steels are mainly used for the manufacture of regular parts for repair of aircraft technique. This is explained by difficulties of obtaining in carbon steels of those or other mechanical properties in conjunction with others for example, of sufficient strength with good toughness.

Carbon steels are divided according to their designation into:

a/ structural steels; soft and medium hard steels with carbon content up to 0.6 per cent / see Fig.23/ are referred to this group of steels;

b/ tool steels; steels with carbon content from 0.6 per cent up to 1.4 per cent / See Fig.23/ are referred to this group of steels.

If one considers the steel from the point of view of its freedom from harmful admixtures, the steels can be classified into commercial quality, high grade steel and extra high grade steel. This concerns both carbon

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steels as well as special alloyed steels. It follows from this that the alloyed steels are not always of high grade, while carbon steels are not always of inferior quality. Thus for instance, alloyed steels carelessly manufactured and contaminated by such harmful admixtures as phosphorus and sulphur would not be considered as high quality steels and vice versa, carbon steels purified from these admixtures would be considered as an extra high quality steels.

All steels manufactured by steel-making plants have a definite chemical composition.

Depending on the chemical composition all steels are divided into grades.

Structural carbon steels of commercial quality are classified by the following grades: CT.1; CT.2, CT.3, CT.4, CT.5, CT.6. Letters "CT" designate steel, while the figure indicates the number of steel. The greater the number of steel, the more carbon it contains.

High grade structural carbon steels are classified by the following grades: 08, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, and 70. No letters are put in front of these grades of steel. It is usually said: steel grade 10, or steel grade 45. Figures of these grades of steel indicate the amount of carbon / average / in hundredth fractions of one per cent contained in these grades of steel.

Extra high grade structural carbon steels are marked in the same way as high grade of steels, but after figure indicating the mean carbon content the letter "A" is

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put , for example , 20A, 30A, 45A, 50A , etc.

Extra high grade tool steels used in the aircraft technique , are classified by the following grades : Y7A , Y8A, Y9A, Y10A, Y12A, Y13A. The letter "Y" designates the steel of the carbon tool-steel class. The digits following this letter denote percentage of carbon contained in the given grade of steel . The letter "A" at the end of steel grade indicates that this steel is improved , has a lower content of harmful impurities / sulphur and phosphorus /, i.e. extra high grade steel. Thus for instance steel grade Y8A means that it is extra high grade carbon tool steel with carbon content 0.8 per cent.

Steels used for the manufacture of parts for aircraft engines and airplanes should meet special requirements , therefore in the aircraft industry and also for the repair of aircraft technique high grade and extra high grade steels such as carbon and alloyed steels are used exclusively.

In these steels , the content of sulphur and phosphorus must not exceed 0.035 per cent. The influence of these elements on the properties of steel has been discussed in chapter 1.

Grades and physical properties of structural steels used in the aircraft industry are indicated in Table 1.

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Table 1

Physical Properties of Carbon Steels Used in the Aircraft Industry

Grades of steel	Carbon content per cent	Shapes of Rolling	Condition of Material	Tensile strength $\frac{kg}{mm^2}$
0.8	0.08	Sheets	Annealed	28
10 and 10A	0.08-0.15	Rods and sheets	Annealed, normalized	32-42
20 and 30A	0.15-0.25	Tubes, sheets	Annealed	40-55
25	0.20-0.30	Rods, forgings	Normalized	43
35	0.30-0.40	Rods, sheets	Normalized, annealed	52
40	0.35-0.45	Rods	Normalized	60
45	0.40-0.50	Rods, forgings, tubes	Normalized	60
50	0.45-0.55	Rods	Normalized	63

Relative Elongation per cent	Brinell hardness HB
26	
24-30	95-143
20-24	112-152
18	121-170
18	148-187
10	160-180
13	170-229
13	179-225

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Steels grades 08, 10, 20 are used for low stressed parts and structures, the manufacture of which is connected with welding, flanging, forging, stamping and other similar operations. These steels possess high plasticity and good weldability.

The parts made of these steels are not subjected to heat treatment with the purpose of raising their strength.

Steel grades 25, 35, 40, 45 and 50 possess higher strength, than the steel grades 08, 10, 20 but are inferior as to their weldability. They are used for the manufacture of bolts, screws, nuts and small forgings.

Physical properties of tool steels are described in Chapter VII entitled "Heat treatment of tools".

Tool steels are used for the manufacture of cutting and percussion tools and measuring instruments. The grade of tool steel is selected depending on the tool application.

Exemplary application of tool steel grades is discussed in Chapter VII.

Carbon steels possess low hardenability. This property of carbon steels is not detrimental to the tools inasmuch as quenched tools possess hard surface case and tough core and therefore are ^{less} brittle and easier stand percussion.

For parts, requiring hardening through, low hardenability of carbon steels is not considered as a defect. The following example is rather descriptive of the hardenability of carbon steels; the rod of Y10A grade steel 50 mm in diameter quenched at the temperature of 800°C hardens to the depth of approximately 4mm.

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The fact that at quenching , the carbon steels require rapid cooling is considered as an imperfection. Furthermore , high thermal stresses develop at rapid cooling , which is fraught with a danger of appearance of cracks in tools , parts , etc.

2. Alloy Steels

It is hard to obtain combination of high physical properties in carbon steels. For instance , at high tensile strength and high hardness , these steels possess low toughness , i.e. they are very brittle.

For the majority of airplane parts and aircraft engine , subjected to the action of static , dynamic and periodic loads , steels with high tensile strength and high toughness are required.

In order that the steel acquires high physical and sometimes other special properties , various elements such as: silicon , manganese , chromium , molybdenum , vanadium , tungsten and others are added to it. Steels into which special elements , noticeably changing the properties of steel , were introduced are called alloyed steels and have a widespread application in the aircraft industry .

The physical properties of steels are dependent on the amount of introduced alloying elements . However , the quantity of introduced elements should be limited. Thus, the increase of the content of the element up to a certain percentage improves the physical properties of steel , while further addition of the element not only does not improve, but on the contrary , lowers the properties of steel.

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According to the application alloyed steels are subdivided into: structural , tool and steels of special application .

Structural alloyed steels possess higher strength , elasticity and toughness than the structural carbon steels. Therefore , the main parts of an aircraft engine and the airplane are made of alloyed structural steels.

Alloy tool steels are used for the manufacture of tools intended for machining of very hard materials and also in those cases when high resistance to tempering is required of the cutting tools , which means that these tools should not lose their properties at heating. These steels possess greater resistance to heating at operation of tools and allow greater cutting speeds .

Steels possessing some outstanding properties are referred to the steels of special application . The properties include: high resistance to corrosion / stainless steels /, high heat resistance / heat resisting steels /, resistance to scale / scale resistant steels /, resistance to wear , etc .

Letter-digit system , for example 18X4BA , is used for marking of alloy steels . What do these letters and digits stand for?

The letters denote the alloying elements , for instance:

H - nickel

M - molybdenum

X - chromium

Г - manganese

K - cobalt

D - copper

C - silicon

Л - phosphorus

B - tungsten

А - aluminum

В - vanadium

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The first two digits in steel grade designation indicate the mean carbon content in hundredth fractions of per cent, while the digits placed after the letters indicate the mean content of the element which is characterized by the given letter. If at this the content of element is lower or close to one per cent, then the digit is omitted. Let us take for example steel grade 30X1A. It contains 0.28-0.35 per cent of carbon, 0.8-1.1 per cent of chromium, 0.8 - 1.2 per cent of manganese, 0.8 - 1.2 per cent of silicon. Letter "A" denotes that this is extra high grade steel with low content of phosphorus and sulphur. Sometimes in order to abbreviate the designation of steel, this system is deviated from. For instance, steel composed of 0.14 - 0.21 per cent of carbon, 1.35-1.65 per cent of chromium, 4.0 - 4.5 per cent of nickel, 0.8 - 1.2 per cent of tungsten should have been designated 18XH4BA. For the sake of abbreviation this steel is often marked 18XHBA.

Depending on the name of alloying elements, introduced into the steel, the latter are called manganese, chromium, nickel, chromium-nickel, chromium-manganese-silicon, etc.

Manganese steels. Manganese increases hardness, strength, wear-resistance and particularly hardenability of steel. The manganese steels possess good weldability.

Ordinary content of manganese in structural steels does not exceed 2 per cent. Manganese steels with carbon content 0.3 - 0.5 per cent and manganese content 1.0-1.5 per cent / for example steel grade 30X1A are used.

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for the manufacture of bolts , axles , gears , and other parts working for wearing.

Steel with the same content of manganese but with an increased content of carbon / steel grade 65 / A / is used for the manufacture of springs.

The increased manganese content in steel / 1.4-1.5% / at corresponding heat treatment sharply increases steel toughness.

Chromium steels . Chromium is one of the widespread, relatively inexpensive alloying elements . It is broadly used in most different steels , increasing their hardness and strength , while retaining at the same time sufficient toughness . Chromium imparts to steel high resistance to corrosion and improves heat resisting properties. It also decreases the susceptibility of steel to overheating at heat treatment and increases hardenability.

Two grades of chromium steel : 15XA and 38XA are used mostly in the aircraft industry. Steel grade 15XA is referred to the group of case hardening steels and is used for the manufacture of small parts of an aircraft engine, instead of steel grade 18H2A and in some cases instead of steel grade 12XH2A. Steel grade 38XA is used to make gears, nuts, bolts and also screw bushings .

Nickel steels . Nickel sharply decreases the critical rate of hardening / nickel steel does not require quick cooling at hardening / and therefore raises hardenability of steel . Nickel steels are apt to the hardening through, even at large dimensions of parts .

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Nickel increases tensile strength and hardness of steel without changing its toughness; it contributes to obtaining of fine-grained structure of steel and decreases the susceptibility of steel to brittleness at tempering and also lowers the susceptibility of steel to overheating.

The following grades of nickel steels are used in the aircraft industry : 13H2A, 13H5A , 21H5A.

Nickel is a scarce metal , therefore nickel steels are substituted by a less expensive steels , such as chromium-manganese steels , which possess physical properties equal to the nickel steels .

As an alloying element nickel is introduced into many grades of steel , and in combination with other alloying elements it imparts to steel besides high strength also special properties / acid resistant , scale resistant and heat resisting steels /.

Chromium-nickel steels . Chromium-nickel steels received a wide application due to the successful combination of their physical properties : high strength , high hardness and high toughness which are provided by simultaneous introduction of chromium and nickel .

The majority of main parts of an aircraft engine are manufactured of chromium-nickel steels.

The following grades of chromium-nickel steel find the most wide-spread application : 12X2H4A , 16XHBA, 40XHBA.

Steel grade 12X2H4A case hardening steel - is used for making of responsible gears , various shafts , piston pins , etc.

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Steel grade 18XHBA is used for the manufacture of crankshafts, reducer shafts and important bolts and pins.

Steel grade 40XHMA is used for the same parts as steel 18XHBA.

Besides the alloying elements of chromium and nickel, the above mentioned steels are alloyed with tungsten and molybdenum which improve the physical properties of chromium-nickel steels.

Chromium-manganese-silicon steels / chromansil/. This steel received an exceptionally wide application in the aircraft building . All responsible parts of aircraft gliders are made of steel grade 30X/CA / chromansil grade/.

The name of the steel grade indicates that chromium, manganese and silicon are used as alloying elements in this steel . An increased content of silicon in this steel ensures a considerable improvement of the strength and hardness.

Recently , alongside with application of chromansil , steel grade 30X/CHA acquired a widespread application , with the latter possessing still better physical properties.

Data concerning physical properties of these steels are given in table 2.

Table 2

Physical Properties of Steel Grades 30X/CA and 30X/CHA			
Steel Grades	Semi-manufactured product	Condition of Material	Tensile strength 6B kg/mm ²
			Relative elongation in per cent
30X/CA	Rods	Hardened and tempered at temperature of 200-250°C	160 7
30X/CHA	Rods	Ditto	175 10

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8. Methods of Determining Steel Grades

Sometimes it is necessary to determine rapidly the grade of steel even though not so accurately, for example at reassortment of steel or in a case of doubt that the part had been manufactured of another steel ^{grade} than specified in the drawing.

For a quick determination of the steel grade, a spark test is applied or drop analysis made, at which the chemical composition of steel is determined.

Spark Test

The spark test is based on the ^{fact} that each steel has its own inherent in it character of sparks. For instance, carbon steel grades produce white stream of sparks with separate stars, whereupon the greater is the content of carbon in steel, the greater is the number of stars, while the spark stream becomes shorter.

The spark test is performed in the following way. A piece of steel or a steel part, whose grade is to be determined is slightly pressed against rotating emery wheel and the colour and shape of the obtained spark stream is studied / Fig. 22/.

In order to avoid mistakes, the spark test should be carried out in a dark room or in a sufficiently darkened premises, applying a coarse-grained emery wheel, observing the uniform conditions of testing. Besides that, it is necessary to bear in mind that for a rapid and secure determination of steel grade at a spark testing, a certain experience is required. This experience may be acquired while observing a spark stream produc-

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ed by a known in advance steel grade.

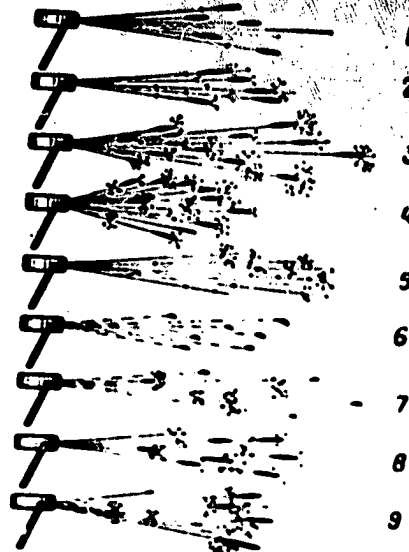


Fig. 22. Determination of steel grade according to spark colour.

Various kinds of sparks for different grades of steel are given in Fig. 22:

1. Low carbon steel with 0.12 per cent of carbon.

The spark is not long, the stream is not dense, the spark lines are continuous, and spark ends are thickened and look like spikes. The spark colour is straw-yellow.

2. Structural steel grade 45 / 0.4-0.5 per cent of carbon. The spark stream looks the same as in previous steel, but at the spark ends besides the thickening there are some stars.

3. Tool steel with carbon content 0.9 per cent. The spark stream is wider and longer, there are more stars and

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they are larger and fluffier and are found both in the stream ends and in its middle. The spark colour is light yellow.

4. Tool steel with carbon content 1.2-1.4 per cent / without tungsten/. The spark stream is short and wide, there are more stars than in the previous steel. The spark colour is white.

5. Manganese steel with 12 to 14 per cent of manganese. The shape of the spark stream looks like that of structural steel grade 45. It differs by the fact that there is no thickening at the spark ends. The spark colour is bright wine-yellow.

6. High speed steel with 14-16 per cent of tungsten. The spark stream is short, narrow, the sparks are dotted at hatchure ends there are round thickenings. The spark colour is dark-red.

7. Steel with 1.3 per cent of tungsten. The sparks look the same as in previous steel, but there are stars in the stream. The sparks are lighter and brighter. Steel grade 18 KHBA has similar sparks.

8. Silicon steel. The sparks, in shape and in colour, are analogous to the medium carbon steel / for example, steel grade 45/, but there are more stars in the spark of silicon steel.

9. Chromium-nickel steel with 1 per cent of chromium and 3 to 4 per cent of nickel. The characteristic sign of the spark is its brightly clear yellow colour.

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Drop Analysis

Determination of steel grade by spark test gives in some cases unsatisfactory results particularly in the absence of a certain experience. There is a surer method of steel grade determination -- the so called drop analysis. With the aid of a drop analysis it is possible to establish the presence of alloying elements in the alloy, and thus to determine the group to which the examined alloy belongs, and sometimes precisely to determine the grade of the alloy. For instance, alloy steels can be subdivided into groups: chromium, nickel, chromanil, chromium-nickel, chromium-nickel molybdenum and other. The drop analysis can be used to determine bronze and brass, forged aluminum alloys and aluminum-silicon alloys "silumins".

The drop analysis may be quickly performed in any conditions directly on the surface of the tested specimen or a part with the aid of a simple apparatus.

The substance of the drop analysis consists of the following. A drop of acid, a mixture of acids or alkali is put on the surface of the tested part. At the place where the drop was put, the metal partially dissolves. In order to obtain the drop reaction to the element, characteristic of the given grade of steel, a special reagent is added to the formed metal solution. The presence and the amount of the determined element are judged by the results of the reaction / change in colour brightness and deposit /.

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Special portable laboratories , in the form of a box--
a portable trunk , with a set of reagents for determinat-
ion of the majority of elements , have been designed to
carry out the drop analysis.

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Chapter IV

THE PRINCIPLES OF HEAT TREATMENT OF STEELS

1. Designation and Essence of Heat Treatment.

The heat treatment includes the heating of steel to a certain temperature, holding at this temperature and cooling with a definite speed, with a purpose of changing the steel structure and its properties. At heat treatment the chemical composition of steel does not change.

The following physical phenomena lies at the basis of heat treatment. Let us visualize the molten steel. At the transition from a liquid to the solid state at temperature of approximately 1500-1400°C the steel crystallizes and acquires a definite structure, however it appears that many alloys, including the steel, change their structure at further cooling / already being in a solid state /. Complete rearrangement of crystals takes place. This phenomena is known as a secondary crystallization, while the temperature at which the secondary crystallization takes place is called-critical temperature.

In order to establish a correct method of heat treatment of steels, it is necessary to know the equilibrium diagram of the iron-carbon alloys / Fig.23/ on which critical temperature of steels with different carbon content are plotted.

The critical temperatures / or critical points/ are designated on the equilibrium diagram of iron-carbon alloys at heating with letter A with an index c, while at cooling -- with letter A with an index r. Thus for in-

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stance, the temperature of the beginning of transformation of α -iron / ferrite/ into γ -iron /austenite / at heating to the temperature of 723°C is designated by AC1, while the temperature of the end of transformation of α -iron into γ -iron is designated by AC3. Points AC1 lie on the horizontal line of the diagram SK, while points AC3 lie on the line GSE.

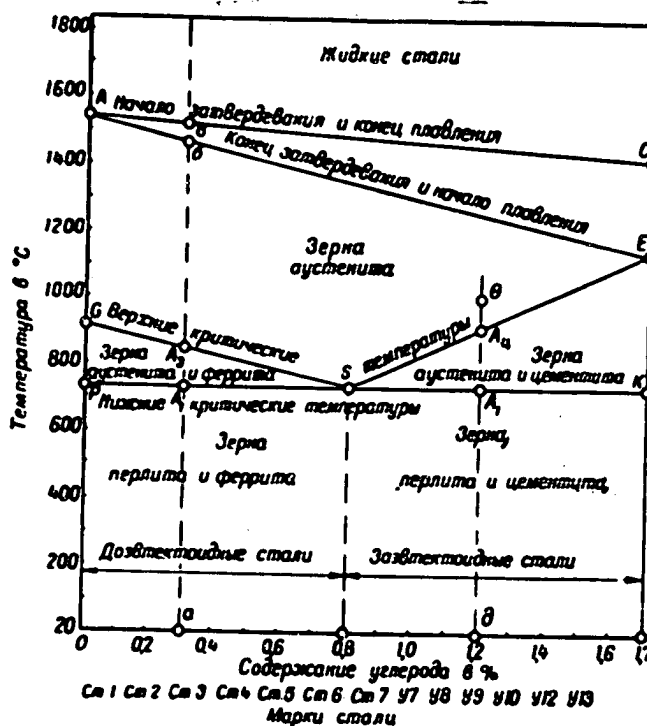


Fig.28.- Equilibrium diagram of iron-carbon alloys.

a/ Temperature in °C; 1 - Hypoeutectoid steels; 2/ Hypereutectoid steels; 3- Grains of pearlite and austenite; 4- Grains of pearlite and cementite; 5-Grains of austenite and ferrite; 6- Grains of austenite and cementite; 7- Upper critical; 8- Temperatures; 9- Grains of austenite; 10- End of solidification and beginning of melting; 11- Beginning of solidification and end of melting; 12- Liquid steels; 13- Carbon content, per cent

Y7, Y8, Y9, Y10, Y11, Y12,
Grades of steel.

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The critical temperatures / points/ in steel have been for the first time discovered by the great Russian metallurgist D.N. Tchernoff. Steel, heated above the critical temperature, sharply changes its structure. Through a rapid cooling it is possible to fix in some steels, that structure, which the steel had above the critical temperature. In carbon steels though it is not possible at cooling to fix the structure forming at high temperatures, however the obtained transition structures considerably improve the physical properties of steel.

Let us follow by which way it is possible to change the structure of carbon steel with carbon content up to 0,8 per cent, with the aid of heat treatment. Prior to heat treatment these steels are composed of ferrite and pearlite grains. If the steel is heated above the critical temperature of A_{CS} , then recrystallization will take place in it, i.e. particles of cementite included in the composition of pearlite grains are completely dissolved in the austenite grains. At this the crystal space lattice of ferrite rearranges from the body-centered cubic lattice into the face-centered cubic lattice.

At temperature below the critical point the austenite will again transform into pearlite and ferrite. A complete transformation of austenite and formation of structure corresponding to the normally cooled steel, requires some time, and can be concluded if the cooling of an alloy proceeds sufficiently slow. If the heated steel is cooled quickly, the austenite may not completely transform into pearlite and ferrite and then the steel will acquire that

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or another transitional unstable structure. The properties of these transitional structures sharply differ from the properties of the slowly cooled steels. Thus, for instance, hardness is sharply improved in the rapidly cooled steel; it becomes strong but brittle due to the forming of transitional structure of martensite.

By cooling the steel from a temperature above the critical point with a different speed, it is possible to influence the change of properties of steel in the desired direction. Herein lies the essence of the heat treatment of alloys.

The equilibrium diagram of iron-carbon alloys shows how structure of steel changes depending on the content of carbon in it / from 0 to 1.7 per cent/. The temperature is plotted on the vertical axis of the diagram and carbon content in per cent on the horizontal line. Above the AC line the steels are in a liquid state / liquid alloy/. The AC line connects the points of beginning of steel crystallization. The crystals of solid solution are formed in the liquid alloy at lower temperatures / below AC line/.

The line on the diagram connecting points AE signifies the completion of solidification of iron-carbon alloys. All alloys below this line are already in a solid state.

Iron-carbon alloys, containing carbon from 0 up to 1.7 per cent, are called steels. Alloys, containing carbon over 1.7 per cent, are called pig iron.

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The author is not going to examine the structure of pig iron, and only characteristic of lines and points of equilibrium diagram of iron-carbon alloys in the field of steels are discussed in this book.

Below AE line all steels are in a solidifying state, in the form of a solid solution, called austenite. The austenite is a solid solution of carbon in γ -iron / having face centered cubic lattice /.

The austenite exists in steel structure without any transformations only at high temperatures / above GSE line/. At lower temperatures the austenite begins to disintegrate.

When carbon content in steel is below 0.83 per cent / such steels are known as hypoeutectoid steels / , then at slow cooling of steel a part of austenite transforms into a pure iron-ferrite, which has the body centered cubic space lattice. This transformation takes place at high temperatures, which correspond to the GS line.

When the temperature drops to 723°C, the austenite grains disintegrate completely and the mechanical mixture of ferrite with pearlite forms in steel. On further cooling, grains of pure ferrite with pearlite remain in steel.

If the carbon content in steel is over 0.83 per cent another picture takes place / such steels are called hypereutectoid /. No formation of ferrite takes place at slow cooling of these steels. At the temperature corresponding to the SE line, cementite separates from the solid solution of austenite, and furthermore, at the temperature of 723°C all austenite transforms into pearlite. Slow cooled hypereute-

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toid steel has a structure of pearlite and cementite.

When steel contains just 0.83 per cent of carbon , at cooling the austenite transforms completely into pearlite.

On the equilibrium diagram of iron-carbon alloy , the GSE line connects the upper critical points AC_3 , at which the structural transformations take place in steel . As it has been ascertained , above these temperatures , the steel has austenitic structure . It may be seen on the diagram, for steels with different carbon content , the temperature of critical point AC_3 is also different . For steel with carbon content 0.83 per cent , the temperature is at the minimum and it equals to 723°C .

The horizontal line FSE connects the lower critical points in steel . At this temperature $/723^{\circ}\text{C}/$ the whole austenite desintegrates completely and the structure of ferrite and pearlite remains in the cooled hypoeutectoid steel whereas the structure of pearlite with austenite remains in the hypereutectoid steel.

In order to provide complete solution of cementite in steel at heat treatment , the latter is heated at $30-35^{\circ}\text{C}$ above the upper critical temperature AC_3 and is held at this temperature for a necessary period of time. Steels with carbon content over 0.83 per cent are heated to the temperature of $740-760^{\circ}\text{C}$ inasmuch as still higher heating causes extensive grain growth , thus lowering the steel strength and its plasticity.

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2. Transitional Types of Steel Structures After Heat Treatment

Besides the above mentioned basic structures of steel - ferrite , pearlite and austenite , there are also in steel the so-called transitional structures : martensite, troostite and sorbite.

These structures form at various speeds of steel cooling and have the name of hardening structures .

M a r t e n s i t e is a product of austenite desintegration and it forms at the fast cooling of steel at hardening. In order to obtain in steel the martensitic structure, it is necessary to heat it above the AC3 point and rapidly cool it in water . The researches of the Soviet scientists Goudtzov and Kurdumov have shown that martensite is a solid solution of carbon in α -iron , but differs from ferrite by a sharp distortion of the space lattice. The ferrite contains usually very little of carbon / up to 0.04 per cent / , while martensite , which is formed at austenite desintegration, may contain carbon in a greater quantity , inasmuch as at the fast cooling of steel , the carbon has no time to separate from the ferrite space lattice . Besides , the carbon atoms embed themselves into crystalline space lattice and sharply distort it. The elemental cell of crystalline space lattice of martensite represents in itself a cube slightly elongated to its height.

The microstructure of martensite / Fig.24/ has a characteristic lamellar structure . The lamellae with thinned down ends , in a cross section plane of micro-cut, look like needles.

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The martensite has an extremely high hardness and low toughness. The martensite hardness increases with the rise of the carbon content in steel, but commencing from 0.6 per cent of carbon it is almost constant $H_{RC} = 62-65/$. The high hardness of martensite is explained by the great distortion of crystalline space lattice. Machine parts with martensitic structure have high internal strains.

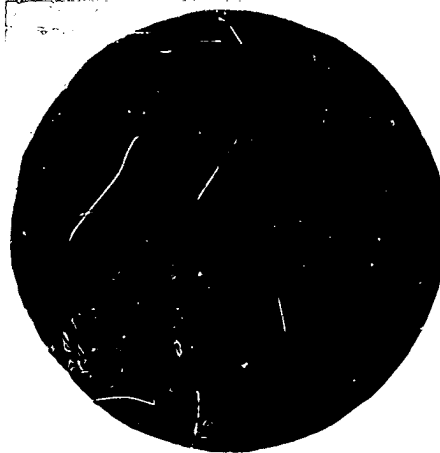


Fig.24. Microstructure of steel hardened for martensite.

Magnified 500 diameters.



Fig.25. Microstructure of steel after heat treatment for troostite.

Magnified 500 diameters.

T r o o s t i t e. If steel with martensitic structure is heated to the temperature of 400°C and held for some time at this temperature and then cooled in the air, the martensite would be transformed into troostite - a mixture of finest globular particles of cementite and ferrite. After etching, its microstructure has a dark point structure.

/-Fig.25/.

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The hardness of troostite is approximately $HRC 40-50$ and higher. The high hardness of troostite is explained by the great density / great fineness / of cementite particles.

The troostite can be obtained at hardening, but at a slower rate of cooling, than at hardening for martensite.

To obtain steel with troostite structure, the steel after heating is quenched in oil, heated water or in the air.

The microstructure of troostite is very desirable for machine parts working for wear or at periodic loads.

S o r b i t e. If the steel with martensitic structure is heated to the temperature of $500-600^{\circ}C$ and held for some time at this temperature, and then cooled in the air, a light and uniform structure of steel can be obtained, in which the particles of cementite are coarser than in troostite and are visible under the microscope at magnification of $\times 500$ and higher / Fig. 26/. This structure is called the sorbite of tempering.

The sorbite structure has a sufficient hardness / $HRC 30-40$ / and good toughness. The machine parts subjected to high stresses and impact loads, usually are heat treated for sorbite.

The structures of troostite and sorbite may be obtained not only by way of additional heating of martensite but also by immediate cooling of steel, heated to the temperature of hardening. In distinction from the troostite and sorbite of tempering, in this case, the above

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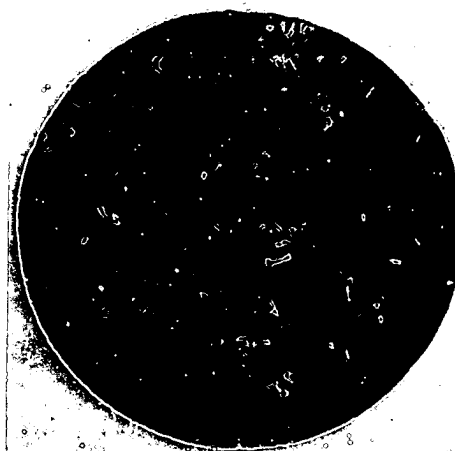


Fig.26. Microstructure of steel after heat treatment for sorbite. Magnified 500 diameters

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mentioned structures are called the troostite and sorbite of hardening.

Depending on the designation of heat treatment and the method of its performance, there are known the following kinds of heat treatment: annealing, normalizing, hardening and tempering.

3. Annealing of Steel

The annealing of steel includes the heating of steel up to the definite temperatures, holding it at these temperatures with a following slow cooling of steel together with a switched off furnace or in a low heat conducting material (ash, sand, etc.) There is high and low annealing. High annealing is described as such, when the temperature at which it is conducted exceeds the critical point A_{c3} ($760-900^{\circ}\text{C}$) by $20-30^{\circ}\text{C}$, low annealing- when the temperature of its performance does not exceed the critical point A_{c1} ($550-650^{\circ}\text{C}$) (see Fig.23).

The annealing is applied when it is necessary:

- a) to relieve steel of internal strains obtained during hardening and forging of steel;
- b) to low the steel hardness (for easing of mechanical working);
- c) to make steel structure fine-grained for increasing of tensile strength, elasticity and impact ductility;
- d) to make the cold worked steel less hard and more plastic (annealing of recrystallization).
- e) to remove the traces of primary crystallization-elimination of chemical nonuniformity, which takes place in cast machine parts.

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Annealing for relieving of internal strains

The internal stresses in steel parts develop as a result of nonuniform cooling of the parts or due to the irregular / too quick/ heating at heat treatment).

The heated steel part starts to cool first on the surface, the surface layers of steel are contracted at cooling and compress the inner layers of the part. As a result of this action both, the outside and inside layers , would be strained. Stresses , developing in the steel parts, due to the difference of temperatures in the part , are called thermal stresses.

Besides the thermal stresses , there also may be stresses developing as a result of structural transformation of steel.

These types of stresses / thermal and structural/ do not disappear leaving no traces at quick cooling of steel after heating , but remain in the part as internal stresses. The internal stresses are harmful , inasmuch as they lower the strength of the steel part and cause the appearance of cracks in the steel.

In order to relieve the steel part of internal stresses , it is necessary to heat it in the furnace to the temperature up to 550-600°C / low annealing / , hold it until heating through and then to cool it slowly together with a switched off furnace or in an ash / in sand/. In this case the slow cooling is necessary only for the protection of the steel part against the repeated rise of internal stresses.

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It is necessary to mention here that the internal stresses are dangerous only for large parts , or parts complex in configuration. In small machine parts the stresses are insignificant and often may be neglected.

In order to relieve the machine parts of internal stresses developed at hardening / quick cooling from high temperatures / the tempering is usually applied / secondary low heating /.

Softening Annealing

Steel of high hardness is difficult to machine by cutting. To make the machining of steel by cutting easier it is desirable " to soften" the steel.

Steels of medium hardness / steel grades 35,40,45,50 and 60 / are machined well , both after annealing and after normalizing and no softening annealing is needed for them.

The softening annealing is applied to the tool steels and may be performed by the two following ways :

1. A blank of tool steel is heated above the critical point AC_1 / see equilibrium diagram of iron and carbon alloys Fig. 23/ , by $20-30^\circ C$ / critical point AC_1 for tool steels, with carbon content over 0.83 per cent equals to $729^\circ C$ / , i.e. to the temperature of $750^\circ C$. The steel blank is held at this temperature for 5-10 hours , and then slowly cooled together with the furnace at the rate of not more than $50^\circ C$ per hour. Such slow cooling is allowed to the temperature of $600-550^\circ C$ after which the tool part may be cooled in the air.

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2. Blank of steel is heated to the temperature of 750°C and after short holding at this temperature is cooled with the furnace to the temperature of $700-600^{\circ}\text{C}$. Then it is heated again to temperature of 750°C and this process is repeated three-four times. This annealing is called pendulum annealing, inasmuch as the temperature at this annealing is not constant and fluctuates near the critical point $\text{AC1} / 723^{\circ}\text{C}/$.

The pendulum annealing is more difficult to perform than the usual annealing, but it may be accomplished in a shorter time.

As a result of softening annealing the lamellar pearlite, which is a usual microstructure of steel, transforms into globular pearlite. Steel with a structure of globular pearlite is easier to machine inasmuch as the cutting tool goes basically over the soft ferrite and rarely meets the cementite grains; whereas, with pearlitic steel the cutting tool must cut the cementite lamellae, which possess an extremely high hardness.

The hardness of carbon tool steels after softening annealing is given in Table 3.

Table 3

<u>Hardness of Tool Steels after Softening Annealing</u>		<u>Brinell Hardness number</u>	
<u>Grades of Steel</u>		<u>HRB</u>	<u>maximum</u>
Y7,	Y7A		91
Y8,	Y8A		91
Y9,	Y9A		92
Y10,	Y10A		93
Y12,	Y12A		95
Y13,	Y13A		96

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Annealing to Fine Grain Structure

After casting or hot mechanical working / forging , stamping , rolling / steel usually has a coarse-grained structure . Such coarse - grain steel is brittle and poorly resists to impact. In order to eliminate brittleness and to make the steel tough , it is subjected to annealing to a fine-grain structure .

Heating of steel for annealing to fine-grain structure should be made to the temperature of 20-30°C above the critical point **Ac3** / for steels with carbon content up to 0.83 per cent , see Fig.23/. At this the temperature of annealing should be carefully observed . Should the annealing temperature be below the critical point **Ac3** , then not all ferrite grains would transform into austenite and no complete desintegration of grains would take place. Should the temperature be considerably above the critical point **Ac3** , then the danger arises of new growth of austenite grains and the steel would have again a coarse-grain structure.

The time of holding at annealing temperature to fine-grain structure must be the shortest; the holding is necessary only for a thorough heating of aircraft steel parts,

The cooling , following the annealing to fine-grain structure , should be carried out slowly together with cooling of the heating furnace until the part becomes dark, after which the treated steel part may be taken out of the furnace and cooled in the air.

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The fracture of a properly annealed steel would have a fine-grain structure.

Changes, taking place in the structure of metal in the process of annealing, are shown in Fig.27.

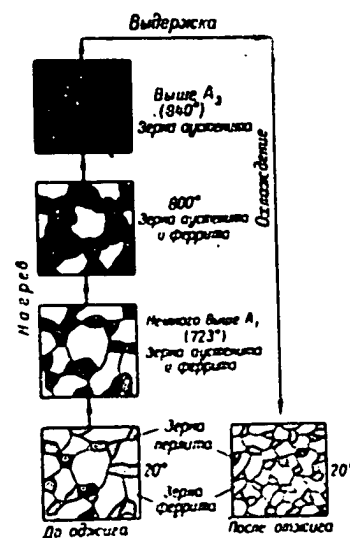


Fig.27. Changes in the metal structure during the process of annealing to fine-grain:

1. Prior to annealing; 2. Ferrite grains; 3. Pearlite grains; 4. Grains of austenite and ferrite; 5. Slightly above A_1 / 723°C /; 6. Grains of austenite and ferrite; 7. Above A_3 / 840°C / austenite grains; 8. Holding time; 9. Heating; 10. Cooling; 11. After annealing.

It can be seen in Fig.27 that prior to annealing the steel has a coarse-grain structure and consists of coarse grains of ferrite and pearlite. If this steel is heated to the temperature of 800°C, its structure would not change, it remains coarse-grained, but as soon as the steel is heated above the critical point A_1 / 723°C /, structural transformations will occur in it, and instead of old grains of ferrite and pearlite new

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grains will form--the grains of austenite, which as also all newly formed grains, will be fine-grained. At the temperature of AC_3 critical point, all grains of ferrite and pearlite will transform into austenite grains and there will be no more original coarse grains left in the steel structure. Now, if this steel is cooled together with the heating furnace or in the air, then out of fine austenite grains, fine grains of ferrite and pearlite will form.

Recrystallization annealing

At working of steel by pressure without heating it gets cold hardened, i.e. it acquires greater strength, hardness and brittleness, but becomes less plastic. It is very dangerous to subject such steel to further working by pressure because of a possible appearance of cracks.

To eliminate cold hardening a recrystallization annealing is applied.

What does the recrystallization of metal mean?

It is known, that in the course of plastic deformation, distortion of the crystal structure takes place. Shifts in the metal grains occur, i.e. the metal is brought to the structurally unstable condition. At such unstable condition the metal spontaneously strives to adopt a more stable condition, but this does not take place only because under the room temperature the atoms are less mobile and therefore the metal structure cannot be reinstated. At high heating, the atoms acquire greater mobility, and at this condition begins the process of recovery of the metal structure, which existed before deformation-- the metal structure, which existed before deformation--the cold hardening. This phenomenon is known as the process of recrystallization.

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In order to reinstate the structure and properties of cold hardened metal , for instance , with the purpose of continuing the working of metal by pressure / let us say, forging / it should be heated above the recrystallization temperature . Such heat treatment is called recrystallization annealing .

Recrystallization annealing of all grades of carbon steels / with carbon content over 0.4 per cent/ is conducted under one and the same temperature of 680-700°C. Under this temperature , the cold hardening is completely eliminated and the steel recovers the properties which it had before the working by pressure. The holding of the metal article under the given temperature should be made until a complete heating through of the whole cross section of the metal article. After such annealing the cooling is done in the air.

The influence of the recrystallization annealing upon the structure of the steel is shown in Fig.28. The cold hardened metal possesses fine , but stretched in one direction grains . After recrystallization annealing, the steel grains also remain fine , but stretching disappears in them.

It is necessary to point out that the recrystallization annealing of steel with a low carbon content / steel grades 10,20,30 and 40 / is not practised , inasmuch as considerable growth of ferrite grains occurs , as a result of which the steel becomes brittle . Therefore , in order to eliminate cold hardening in these steels , the process of normalizing is applied / see below/.

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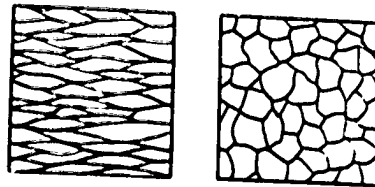


Fig. 28. The change in the metal structure after the recrystallization annealing .

1. Before annealing . 2. After annealing .

In steel with moderate hardness and in hard steels with carbon content over 0.4 per cent : steel grades 60, 60,70, Y7, Y8 , etc . , there are considerably less ferrite grains and therefore the danger of their growth does not exist.

4. Normalizing

The process of normalizing consists in heating of steel to the temperature exceeding the critical point A_{C3} / see Fig. 28/ by 30-50°C, in holding for a short period of time and in a consequent cooling in the still air without draught/. The normalizing takes the intermediate place between the hardening and annealing. It differs from annealing by higher rate of cooling , and from hardening by slower rate of cooling .

As a result of normalizing , a complete recrystallization of steel takes place ; the steel acquires fine-grain and uniform microstructure , as compared with the

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initial condition . After normalizing , as compared with annealing , the steel is known to possess greater strength and hardness , but lesser plasticity.

The normalizing is more advantageous than annealing, since immediately following the heating , the steel blank is taken out of the furnace and cooled in the still air , while the furnace can be used for other heat treating operations , whereas at annealing the blank is cooled after heating together with the furnace , after which the furnace must again be heated for the following operations.

The normalizing is usually utilized instead of annealing for forged and rolled billets , prior to their mechanical working.

For low carbon steels / steel grades 10,20,30 / the difference in physical properties after annealing and normalizing is rather insignificant , therefore , as a rule, no annealing is applied , but instead , normalizing is used for it, as a much cheaper heat treating operation.

For medium carbon content steels / steel grades 40 and 45/ , the difference in physical properties of normalized and annealed steels is greater , but even these steels are often subjected to normalizing , when steel with an increased strength and hardness is required without application of hardening and the consequent tempering.

For less important aircraft parts made of steel grades 40,45,50 , the normalizing yields quite satisfactory physical properties ; for important aircraft parts made of the same steel grades , hardening , with a consequent high drawing , should be applied .

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The normalizing is often utilized also to improve the structure of welded seams of aircraft parts, manufactured by welding of low carbon steels / for instance steel grade 20/.

5. Defects at Annealing and Normalizing

Following are the kinds of defects often encountered at annealing and normalizing :

- 1/ Overheating.
- 2/ Overburning.
- 3/ Decarburization.

The steel is considered overheated in that case, when the temperature of annealing or normalizing is much higher than it is required for standard annealing or normalizing of the given grade of steel. It occurs more often when the measuring instruments controlling the furnace temperature are incorrectly calibrated and due to which fact the temperature of the furnace is not properly regulated. The overheating can be corrected by a secondary proper annealing.

The overheating is characterized by the fact that as a result of heating to temperatures considerably exceeding the temperature of the critical point A_{C3} , the structure of steel becomes coarse grained. The overheating can be detected by examining the fracture of control specimens, heat treated together with machine parts, - the structure of the specimen in the fracture will be coarse grained.

The overheated steel is very brittle. The structure of the overheated steel is shown in Fig.15.

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The overburning of steel occurs in the case when the steel was overheated and there was an oxidizing atmosphere in the furnace. The overburning is characterized by the fact that a heavy layer of scale appears on the surface of the overburned steel parts, under which lies the decarburized and oxidized layer of steel.

The overburning may be corrected only in that case, when the thickness of the overburned layer does not exceed the tolerance for machining. In this case the overburned layer should be removed and the part is subjected to the repeated proper annealing. When the overburned layer is greater than the tolerance for machining, then the part cannot be repaired by a repeated heat treatment.

The decarburization consists in that, that at annealing or normalizing the carbon contained in steel burns out of the upper layer, thus decreasing the strength of the upper steel layer. It is dangerous only for the parts having their final dimensions and in this case the part is rejected.

If the decarburized layer does not exceed the tolerance for mechanical working, then it is not dangerous and can be removed by machining.

6. Hardening of Steels

What does the hardening mean

The process of hardening of steel consists in its heating above the critical point AC₂ / See Fig.23/ by 20-300C, holding it for some time at this temperature and consequent rapid / sharp/ quenching.

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The purpose of the hardening is to impart high strength , elasticity and hardness to the steel part which can not be obtained at annealing or normalizing.

Hardening for martensite , when the whole carbon remains in a solid solution is known as a full hardening of steel. The hardening for sorbite or troostite can be considered as a transitional form of heat treatment from annealing and normalizing to hardening for martensite.

Various hardening or cooling mediums / water, oil, air , etc. / are used to obtain different rates of quenching.

Quenching mediums used at hardening

Water , mineral oil , air, salts , etc. are used as quenching mediums at hardening of steel.

For hardening of carbon steels for martensite, rapid cooling is required only at an interval of temperatures 650 to 400°C ; if at this interval of temperatures , the carbon steel is cooled slowly , then no martensite is obtained; but sorbite or even pearlite appear in the steel structure.

Bearing in mind these peculiarities it is quite imperative to select correctly the cooling medium for such steels.

Rates of quenching of carbon steel within two intervals of temperatures in different cooling mediums are shown in Table 4.

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Table 4.

**Rates of quenching of steel in different cooling
mediums**

Cooling mediums	Rate of quenching at degree/sec. at interval of temperatures	
	650-550°C	300-200°C
Water at temperature of 18°C	600	270
Water at temperature of 26°C	500	270
Water at temperature of 50°C	100	270
Water at temperature of 74°C	30	200
Solution of sodium hydrate /10%/ in water , having the temperature of 18° C	1200	300
Solution of common salt /10%/ in water, having the temperature of 18°C	1100	300
Solution of sulphuric acid /10%/ in water , having the temperature of 18°C	750	300
Emulsion of oil in water	70	200
Mineral machine oil	150	30
Transformer oil	120	25

Water and oil are the most widely used quenching mediums .

Water cools intensively at interval of temperatures 650-550°C , but it also intensively cools in the range of temperatures of martensitic transformation /300-200°C/, which is undesirable , inasmuch as the cooling in this

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range must proceed slowly in order that the disintegration of austenite into martensite should be completed. This is a basic deficiency of water quenching. As can be seen from the Table 4, the change in water temperature itself sharply influences its hardening ability at the temperatures of 650-550°C and at the same time it does not influence the rate of cooling in the range of martensite transformation.

For example, water having the temperature of 18°C cools the metal part at an interval of temperatures of 650-550°C with the rate of 600°C per second; while the same part cooled to the temperature of 30°C would be cooled / at an interval of 300-200°C / in the same water with the rate of 270°C per second. If the given water is heated to the temperature of 50°C, then at the interval of temperatures of 650-550°C, the metal part would be cooled in it with the rate of 100°C per second; at an interval of temperatures of 300-200°C the metal part would be cooled at the rate of 270°C per second.

Up till now there has not been found any method to decrease the intensity with which the water cools the steel at an interval of temperatures of 300-200°C.

The presence of salts and dissolved gases in water changes greatly its quenching ability. For instance, 10% solution of common salt / chloride of sodium / cools the steel almost 2 times quicker than the pure water at the same temperature / see Table 4/. The distilled water cools

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steel 2 times slower than the water taken from the water main. The presence of dissolved gases in water decreases its quenching ability. Therefore boiled water, or water used for hardening, quenches steel more intensively than the fresh water, since there are many dissolved gases in this water and its quenching ability is decreased.

In emulsion of oil in water the process of quenching proceeds in the same way as in the preheated water. But neither hot water, nor emulsion solution in water, cooling at an interval of temperatures 650-550°C, approximately with the same rate as the oil, can compete with it at the interval of low temperatures / 300-200°C/ and therefore they cannot substitute the oil. At the interval of low temperatures the oil cools at the rate of 30°C per second, whereas water and water emulsions -- at the rate of 200-300°C. In this connection, as can be seen further, for many steels, oil is used as a quenching medium and not hot water or emulsion.

In comparison with water, oil possesses 3-4 times lesser quenching ability at the interval of temperatures of 650-550°C, but cools almost 10 times slower than the water at the interval of martensitic transformation /300-200°C/.

It is necessary to mention, that the oil has another positive property: it is not sensitive to the change of temperature and possesses the same hardening ability both at 20 and at 100°C.

Since the rate of cooling at various intervals differs, it is possible to choose for hardening not one, but

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two quenching mediums , and firstly to quench the steel in one and then in another medium.

Methods of Quenching of Machine Parts at Hardening

How to quench correctly machine parts at hardening. As it is known , high internal stresses / thermal and structural/ arise at quick cooling , which lead to the warpage of parts and in some cases to the formation of cracks. Therefore , while conducting the hardening all measures should be taken to decrease these dangerous stresses.

As it has already been mentioned, the thermal stresses arise due to non-uniform cooling of steel . Nonuniformity in cooling would be the greater , the faster the cooling proceeds, and consequently the danger of warping would be greater.

The structural stresses arise because of the rearrangement of crystalline space lattice at heating above the critical temperature. At cooling from the critical temperature the structural stresses may be combined with thermal. If structural and thermal stresses are of the same symbol , then the total value of inner stresses increases; if they are of different symbol , then the summarized stresses decrease. The structural stresses remain in the metal part even after its complete cooling. The inner stresses , remaining in the part after its complete cooling , are called residual stresses .

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After hardening the steel always remains in a strained condition, therefore following hardening, the steel should be subjected to tempering which is a radical measure to eliminate the residual internal stresses in the steel part.

The internal stresses are particularly dangerous for high carbon steels and steels with low plasticity. In steels with high plasticity the internal stresses are removed by deformation inside the metal grains and never exceed the tensile strength of steel. It is an entirely different matter when the metal is nonplastic, the internal stresses in it are not removed by deformation and they may exceed the tensile strength of steel.

From the point of view of decreasing the internal stresses the hardening should be carried out in such cooling medium which would ensure the best physical properties and decrease the internal stresses inevitably arising at hardening. There are several methods of cooling at hardening. Therefore it is necessary to select out of them the simplest ones ensuring the necessary properties and guaranteeing against possible defects.

Hardening in one cooling medium

Hardening in one cooling medium is the most simple. It is performed in the following way. The part heated to a certain temperature is submerged into the cooling medium where it remains until complete cooling.

Sometimes, in order to decrease the internal stresses, the steel part is held for a certain time in the air -- "prescooled," before it is submerged in the cooling liquid.

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Sometimes, in order to decrease the internal stresses, the steel part is held for a certain time in the air -- "precooled," before it is submerged in the cooling liquid.

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For machine parts made of carbon steels over 5 mm in diameter , the cooling medium is water , while for parts of smaller diameter and for alloy steels the oil serves as a cooling medium.

Hardening in two cooling mediums

The essence of this hardening consists in that that the heated steel part is firstly submerged in one cooling medium and then into another . At such hardening the internal stresses in the parts would be the lowest.

In order to obtain steel of high hardness , i.e. to obtain martensite grains out of austenite grains , rapid cooling only in the interval of temperatures of 650-400°C is required , otherwise the austenite grains would transform into troostite grains or sorbite grains and the steel would become soft. This takes place because in the interval from the temperatures of heating the steel part for hardening to the temperature of 400-300°C, the austenite grains are very unstable and at slow cooling easily transform into troostite or sorbite grains .

If the steel part is rapidly cooled to the temperature of 400-300°C, the austenite grains would not have enough time to transform into sorbite or troostite grains and martensite structure would be obtained inasmuch as at the temperature below 400-300°C, the austenite can transform only into martensite . Further cooling of steel part can be done at a considerably slower rate. This is firstly by submerging the part into water and then by quickly transferring it from the water into the

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oil for a complete cooling . The difficulty of such hardening lies in the fact that it is hard precisely to determine the time of holding the part in the water , required for its cooling to the temperature of 400-800°C.

Actually , the moment of transferring the part from the water into^{the} oil is determined by the termination of vibration of tongs with which the part is held , or by the termination of the low heard ringing sound resulting from vigorous boiling of water around the part .

If the part is held in the water longer than necessary i.e. , overcooled , then great internal stresses , same as if the part was hardened in one medium / water/, would arise in it.

This method of hardening can be applied only for small parts which in more or less equal degree may be cooled across the whole section. This method is especially widely used to harden tools made of high carbon steels. The application of this method requires from the worker, performing the hardening , high skill .

The Methods of Submerging of Steel Parts Into Cooling Medium at Hardening

The method of submerging the part into the cooling medium is particularly important for decreasing of internal stresses.

If , for instance , a rectangular long bar is submerged into cooling medium vertically , its walls would cool uniformly causing minimum of warping. If the steel bar is submerged " flat ways" , then the upper and the lower side surfaces would cool at different rates. This would cause strong warping of the bar.

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When submerging the heated parts into hardening medium it is necessary to observe the following basic rules:

1. If the steel article consists of a thin and thick parts , then the thick part would be submerged into the cooling medium at first.
2. If the part has long extended form / taps,drills, reamers/ , then it should be submerged strictly vertically : otherwise it would warp.

Fig.29 shows the correct and incorrect methods of submerging steel parts into the cooling liquid.

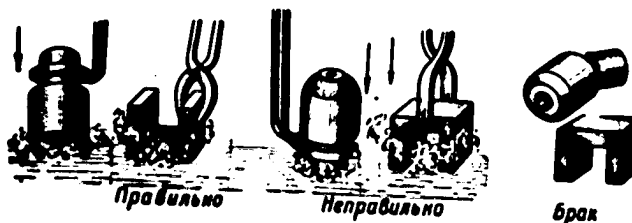


Fig.29. Examples of correct and incorrect submerging of metal articles into cooling medium.

1. Correct; 2. Incorrect; 3. Waste .

In order to harden only a part of the metal article, a local hardening is applied , which is basically carried out by the two following methods :

1. The portion of the metal part , which is subjected to hardening , is heated and thereupon the part is completely submerged into the cooling medium. As a result of this , the heated portion of the part is hardened and non-heated one is left unhardened. The above

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method of local hardening of metal parts may be accomplished by dipping into the lead or salt bath of only that portion of the part, which it is necessary to harden.

2. The metal part is heated completely in the furnace, but only that portion of the part is dipped into the quenching solution, which should be hardened.

The above mentioned methods of local hardening may be used only when it is necessary to harden one of the ends of the metal part. These methods of hardening cannot be used for hardening of the middle part of the article.

The following method of hardening of separate portions of the metal part is applied: the portion not subjected to hardening is covered with a fire clay or asbestos; the coated portions of the part are not subjected to quick heating and also cooling, and therefore the part at these portions remains unhardened. Some examples of coating of metal parts before hardening are shown in Fig. 20.

Protection of separate parts of steel articles against hardening may be effected by some other method.

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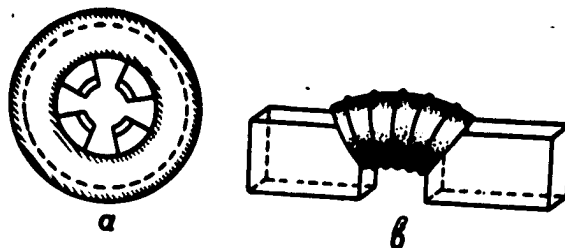


Fig.30. Examples of coating the portions of metal articles to prevent hardening.
a/ protection of the external portion of the threading die; b/ protection of the middle portion of the lock.

Fig. 31 shows a milling cutter prepared for hardening of its external part. The internal orifice of the milling cutter is protected against penetration inside of it of the cooling medium, and consequently is protected against hardening, because a steel bolt had been screwed inside of it with washers under the bolt head and the nuts and asbestos gaskets underneath.



Fig.31. The cross-section of the milling cutter prepared for hardening :

1/ bracing bolt; 2/ asbestos gasket ; 3/ washer.

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Sometimes it is required that the core of the metal article be tough, while its outside surface possesses high hardness and strength. In this case, surface hardening is applied with the outside surface of the article being heated only. At this kind of hardening the outside surface of the article will harden while the core, either remains unhardened altogether, or hardens partially. When heating of the metal article for such kind of hardening, the time of holding should be shorter, than at an ordinary hardening; the heating is regarded as completed when the outside surface of the article acquires the colour of the bottom and the walls of the heating furnace.

Defects at Hardening

The following defects at hardening are frequently encountered :

1. Hardening cracks.
2. Warping of metal parts.
3. Insufficient hardness.
4. Increased brittleness.
5. Decarburization and oxidation of steel articles surface.

Hardening cracks are caused by high inner stresses arising in the parts resulting from the fast rate of cooling. They often appear at the points of sharp transition from the massive to the thin portions of the part, between projecting parts and at places of undercuts. Large metal parts are more disposed to the formation of cracks, small parts, simple in shape are less susceptible to crack formation.

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Fig. 32 shows a crack which appeared in the part in the process of its hardening .



Fig. 32. Hardening Cracks on the metal part.

The metal part with hardening cracks is rejected.

In order to avoid the appearance of hardening cracks, it is necessary to decrease the rate of cooling of the part in question . This can be achieved by way of hardening the part in the oil , instead of water , by quenching in hot water and by hardening of the part in water with a consequent transferring of it into the oil for complete cooling.

Which of the methods of hardening should be applied may be decided separately in each individual case. However , it is necessary to bear in mind that always, where it is possible , the quenching in oil instead of water is preferable , since at oil quenching the danger of crack appearance is sharply decreased .

In order to prevent formation of the inner stresses , it is recommended not to cool the part completely in the quenching medium , but to take it out of the cooling tank at the temperature of 100-150°C and complete its cooling in the air.

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Warping of metal parts is also due to the great inner stresses.

Particularly great stresses are apt to appear in the steel parts when they are hardened for martensite, since the latter causes quite appreciable volumetric changes in the steel part.

Insufficient hardness is caused by the lowered heating temperature for hardening, underholding of metal in the furnace, insufficiently intensive cooling. This kind of defect may be eliminated by rising of temperature in the furnace or by way of increased holding of steel at heating for hardening. If the hardness is low, due to insufficiently intensive cooling, then it is necessary to shake the steel part vigorously during its submerging into the water or to change the cooling medium.

Increased brittleness appears as a result of quenching from the temperature above the required one for hardening of the given grade of steel. At this, the grain growth of austenite takes place, as a result of which a coarse grained steel structure is formed. The brittleness is detected at the mechanical testing.

The brittleness of steel can be eliminated by the repeated hardening from the normal temperature / for the given grade of steel/.

Decarburization and oxidation of steel articles
surface.

At high heating of steel in the furnace, the oxygen of the air may combine with the carbon contained in steel or with the iron itself / ferrite /.

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In the first case the steel part is subjected to decarburization, while in the second case a scale is formed on it. In order to avoid these defects it is necessary to create a reducing atmosphere in the furnace.

Frequently, after hardening of steel parts, some nonhardened spots, the so-called soft spots, i.e., sections with decreased hardness, are detected. They are caused by the fact that, at submerging of steel parts into the water, the steam jacket formed on the part's surface had not been washed off properly. This defect can be eliminated by a repeated hardening.

7. Tempering of Hardened Steels

Designation of tempering

Tempering is not a separate and independent heat treating operation and usually follows the hardening. The tempering consists in heating of steel, after hardening, to the temperature below the critical point / ACl point, see Fig.23/ and the consequent slow or quick cooling.

The tempering imparts the material of which the parts are made, the necessary plastic properties and also removes the internal stresses developed in the steel at hardening.

The most favourable structure, for the majority of structural steels, is sorbitic microstructure. Sorbite possesses a rather high strength and great toughness. Therefore, in most cases, the heat treating operations are conducted for sorbitic structure.

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How is the sorbitic structure obtained in steel?

It is possible to conduct the heat treatment in such a way as to obtain sorbite at once, however, it is rather difficult to select the rate of cooling at which the sorbitic structure can be formed, and besides that, the inner stresses developed in steel at hardening would remain in the steel parts. Therefore, the hardening of steel is performed at a great rate of cooling resulting in the formation of martensite and troostite after which the steel part is subjected to tempering.

The martensite, possessing high tensile strength and great hardness, has a low impact ductility, i.e. it is brittle. The constructional steels must not be brittle and therefore, they are subjected to tempering immediately after hardening. At tempering of steel the grains of martensite and troostite, obtained as a result of hardening at a great rate of cooling, transform into the grains of sorbite and the inner stresses developed at hardening are removed.

The tempering is also necessary after hardening of tool steels. The hardening of these steels is conducted for martensite, after which they are subjected to tempering.

The tempering of tool steels helps to eliminate the brittleness of steel and also removes the inner stresses. It is true, that at this operation the steel becomes somewhat softer, but this can be tolerated.

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Kinds of Tempering

There are three kinds of tempering :

1. **Low tempering**. The temperature of tempering is $200-250^{\circ}\text{C}$. At this tempering no structural changes are observed. This process decreases in some way the brittleness of steel and removes the inner stresses developed in steel after hardening.

2. **Medium tempering**. The temperature of tempering is $300-400^{\circ}\text{C}$. At this temperature the martensitic structure transforms into troostitic structure. The medium tempering is applied to steel parts which must possess the hardness in the range of $HRC-40-45$.

3. **High tempering /drawing/**. This process of tempering is the most widespread and broadly used for constructional steels. The temperature of drawing is $500-600^{\circ}\text{C}$. In this case the martensitic structure transforms into sorbitic structure. This process of tempering in combination with the previous hardening of steel is called the improving treatment.

The selection of the kind of tempering depends on the steel part application.

For cutting tools / drills, taps, milling cutters, etc./ made of tool steel, it is necessary to apply low tempering, since high hardness is required to be maintained / the hardness at low tempering, on condition of correctly conducted hardening, would be $HRC=60-65$.

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For percussion tools, where high toughness is required, the tempering temperature must be considerably above 200-250°C. However, the toughness not always increases with the rising of temperature. It is necessary to bear in mind that some chromium-nickel and chromium-manganese steels are susceptible to the tempering brittleness.

For machine parts made of alloyed steels, it is particularly important to choose correctly the tempering temperature. For example, the steel "chromansil" has a very dangerous "downfall" of impact ductility. Therefore, it is not possible to judge, whether the heat treatment of steel has been conducted correctly by checking the steel hardness, inasmuch as at one and the same hardness the impact ductility of steel may be different.

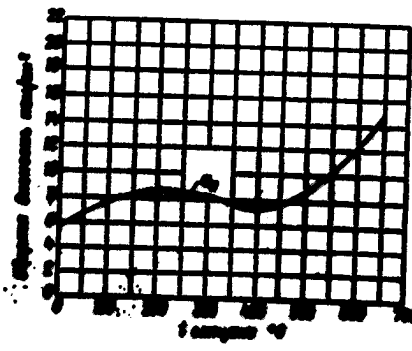


Fig. 88. Change of impact ductility of "chromansil" depending on the tempering temperature.

(1) t of tempering °C. (2) impact ductility kg/cm²

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Fig. 33 shows the change of impact ductility of "chromansil" steel depending on the temperature of tempering.

As can be depicted in Fig. 33 the most dangerous tempering temperature for "chromansil" is 400°C .

It is very important to conduct the tempering of steel parts immediately after hardening. High internal stresses, developed in steel at hardening, may cause cracks in steel parts, if they are not subjected to tempering after hardening even after the lapse of several hours. It is particularly important for steel parts of intricate shape. In order to avoid the appearance of cracks, as it has been mentioned before, it is not necessary to cool the part completely in the quenching medium, but at reaching the temperature of $100-150^{\circ}\text{C}$, it is better to take the part out of the quenching tank for its proper hardening.

The tempering, conducted immediately after hardening, often provides a full guarantee against the development of hardening cracks.

6. The Time of Holding the Steel Parts at Temperatures of Hardening and Tempering.

The time for holding of steel parts at temperatures of hardening and tempering is determined dependent on the cross-section / thickness/ of the part and its configuration. At the beginning, it is necessary to determine the coefficient of the part's shape, which depends on its configuration. The coefficients of the shape of steel parts of different configuration are given in Fig. 34. In order

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to determine the time of holding the steel parts at hardening temperature, the actual thickness of the part / in mm ./ is multiplied by the coefficient of the part's shape and then the time indicated in Table 5 is added to the obtained figure.

Table 5.

Dependence of the time of holding at hardening on
the specimen's thickness

Conditional thickness of steel part / actual thickness of the part multiplied by coefficient of the part's shape /.	Time of holding at hardening temperature
Up to 16 mm	1 minute by 1 mm of conditional thickness + 3 minutes
17 -19 mm	20 minutes
20 mm and over	1 minute by 1 mm of conditional thickness.

The time of holding is counted from the moment of reaching the required temperature in the furnace after charging of steel parts.

Example 1. What time of holding is required at heating of bolts 12 mm in diameter for hardening. If we consult the Fig.84, we find that the coefficient of the shape for the bolt / cylindrical form / is 1.0. By multiplying the cross section / thickness / of the bolt by the coefficient of the shape we obtain number

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12 / i.e. 12 mm of conditional thickness/; from Table 3 we determine that to this number 12 it is necessary to add three minutes. Thus, the time of holding at heating for hardening of bolts 12 mm in diameter equals 15 minutes.

1 Shape of Steel Part	2 Coefficient of Shape
--------------------------	---------------------------

0.75

1.0

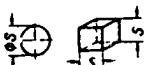
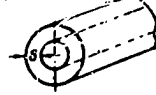
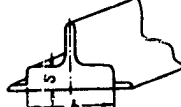
1.5

1.5

2.0

From 4 for long tubes or tubes with closed ends, to 1/3/ 2 for short tubes with open ends

At $b \approx 2S - 1.5$ } Coefficients
at $b \approx 3-4S - 1.75$ } of the shape
at $b > 4S - 2.0$ } 1/4/

Форма детали	Коэффициент формы
	0.75
	1.0
	1.5
	1.5
	2.0
	От 4 для длинных труб или труб с закрытыми концами, до 2 для коротких труб с открытыми концами
	При $b = 2S - 1.5$ при $b = 3 - 4S - 1.75$ при $b > 4S - 2.0$

1/34/ Fig. 34. Coefficients of steel parts shapes

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Example 2. It is necessary to harden a short tube with wall thickness 2 mm / for instance , from steel grade 80X¹CA /. The coefficient of the shape for this tube is 2. Then the time of holding is equal to the tube thickness 2 mm x 2 / coefficient of the shape / + 3 minutes = 7 minutes .

Example 3. The time of holding for a flat plate / sheet material / 5 mm thick equals :

$$5 \text{ mm} \times 2 / \text{coefficient of the shape} / + 3 \text{ minutes} = 13 \text{ minutes}$$

Thus, each steel part , according to its shape, may be referred to one of the shapes , indicated in Fig. 34. When the coefficient of the shape is known , then it is easy to determine the time of holding at the temperature of hardening.

The time of holding at tempering depends also on the conditional thickness / coefficient of the shape multiplied by the actual steel part's thickness / and on the temperature of tempering .

In table 6 given below , the data are specified, by which the time of holding is determined dependent on the temperature of tempering and the thickness of steel parts.

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Table 6.

Dependence of the time of holding at tempering
on the thickness and temperature of
tempering

Temperature of Tempering		
up to 300°C	from 300 to 400°C	over 400°C
2 hours + 1 min. per 1 mm of con- ditional thick- ness of steel part	20 minutes + 1 mi- nute per 1 mm of conditional thick- ness of steel part .	10 minutes + 1 minute per 1 mm of conditional thickness of steel part

Example . It is necessary after hardening to tem-
per bolts 16 mm in diameter / for instance , bolts of
steel grade 38XA or 30X / CA /. The coefficient of the
shape for bolts equals 1.0 / see Fig.24/. The tempera-
ture of tempering is from 300 to 400°C / depending on the
required properties /. The time of holding for bolts of
the given diameter is :

thickness of bolt 16 mm x 1.0 / coefficient of the
shape / + 20 minutes = 36 minutes.

If the tempering is conducted from the temperature
above 400°C, the time of holding equals :

thickness of bolt 16 mm x 1.0 / coefficient of the
shape / + 10 minutes = 26 minutes.

Chapter V**REGIMES OF HEAT TREATMENT OF STEELS****1. Carbon steels**

The chemical composition of carbon steels used for repair of aircraft technique is shown in table 7.

Table 7.**Chemical Composition of Carbon Steels**

Grade of steel	Chemical Composition, per cent			
	Carbon	Silicon	Manganese	Phosphorus
10A	0.05-0.15	0.17-0.37	0.35-0.65	0.035
20A	0.15-0.25	0.17-0.37	0.35-0.65	0.030
35A	0.30-0.40	0.17-0.37	0.50-0.80	0.035
45A	0.40-0.50	0.17-0.37	0.50-0.80	0.035
70	0.65-0.75	0.15-0.30	0.45-0.75	
Y8A	0.75-0.85	not over 0.30	0.25-0.35	
Y9A	0.85-0.94	not over 0.30	0.20-0.30	
	Sulphur		Carbon	
	c		n r	
	0.035			
	0.035		0.30	
	0.035		0.30	
	0.035		0.20	
	0.080		0.30	
	0.080		-	
	0.080		-	

Regimes of heat treatment for these steels are given below.

Steel grade 10A. The hardening effect of this steel is insignificant, since there is very little carbon in it.

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Chapter XREGIMES OF HEAT TREATMENT OF STEELS1. Carbon steels

The chemical composition of carbon steels used for repair of aircraft technique is shown in table 7.

Table 7.Chemical Composition of Carbon Steels

Grade of steel	Chemical Composition, per cent			
	Carbon	Silicon	Manganese	Phosphorus
10A	0.05-0.15	0.17-0.37	0.35-0.65	0.035
20A	0.15-0.25	0.17-0.37	0.35-0.65	0.030
35A	0.30-0.40	0.17-0.37	0.50-0.80	0.035
45A	0.40-0.50	0.17-0.37	0.50-0.80	0.035
70	0.65-0.75	0.15-0.30	0.45-0.75	
Y8A	0.75-0.85	not over 0.30	0.25-0.55	
Y8A	0.85-0.95	not over 0.30	0.20-0.30	
	Sulphur			
	Copper			
	Nickel			
	6	7	8	
	maximum			
	0.035	0.25	0.30	
	0.035	0.30	0.30	
	0.035	0.30	0.30	
	0.035	0.20	0.30	
	0.030	0.30	0.30	
	0.030	-	-	
	0.030	-	-	

Regimes of heat treatment for these steels are given below.

Steel grade 10A. The hardening effect of this steel is insignificant, since there is very little carbon in it.

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Steel grade 10A is subjected to normalizing , high and low annealing ; the temperature of normalizing and high annealing is $890 \pm 10^{\circ}\text{C}$, the temperature of low annealing $700 \pm 10^{\circ}\text{C}$.

Steel grade 10A has good welding properties and can be welded by all types of welding . It is used for welded and stamped machine parts. The hardness of this steel after normalizing should be $H_{\text{RC}} = 40-45$.

Steel grade 20A is used for welded and stamped machine parts of medium strength / submotor frames of light airplanes type "O-2" , exhaust manifolds , etc./. This steel is subjected to normalizing , high and low annealing ; the temperature of high annealing and normalizing is $880 \pm 10^{\circ}\text{C}$, of low annealing $700 \pm 10^{\circ}\text{C}$. The hardness of this steel after normalizing should be $H_{\text{RC}} = 63-81$.

Steel grade 35A is used for the manufacture of bolts, nuts , screws , washers and other small parts. This steel is subjected to normalizing , hardening , high and low annealing ; the temperature of high annealing , normalizing and hardening is $860 \pm 10^{\circ}\text{C}$; the temperature of low annealing is $700 \pm 10^{\circ}\text{C}$. The hardness of this steel after normalizing should be $H_{\text{RC}} = 77-91$.

Steel grade 45A is used for bolts, pins , screw caps, nuts and other small parts . It is welded satisfactory by MIG and atomic - hydrogen welding , but is not welded by gas welding .

Steel grade 45A is subjected to normalizing , high and low annealing ; the temperature of high annealing and normalizing is $850 \pm 10^{\circ}\text{C}$, of low annealing $700 \pm 10^{\circ}\text{C}$. It is also subjected to hardening and tempering. 3074

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Methods of hardening and tempering of machine parts made of this steel are given in table 8.

Table 8.

Temperatures of Hardening and Tempering of Machine parts

Made of Steel grade 45A					
Thick- ness of Machine part	Harden- ing Tem- perature °C	Cool- ing Medium	Temper- ing tempe- rature °C	Hard- ness HRC	Tensi- le Strength kg/mm ² 68
Up to 8 mm	820±10°C	Oil	570-680	20-25	70-80
	820±10°C	"	400-450	33-39	110-130
Over 8 mm	820±10°C	"	570-620	33-39	70-80
	820±10°C	"	470-520	20-30	80-100

Hardening in water of machine parts made of steel grade 45A is not recommended in order to avoid the appearance of hardening cracks. The temperature of hardening and tempering is chosen depending on the thickness of the machine part, required hardness and tensile strength as stipulated in Table 8.

The time of holding of steel parts in the furnace at the temperature of hardening and tempering is determined dependent on their thickness, as it has been described before / see pages 86-90/.

Steel grade 70 is used for helical springs / steel wires BC and OBC /. The springs are subjected to tempering after winding; the tempering temperature is 260 - 300°C.

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Steel grades Y0A and Y0A are used for flat springs. These steels are subjected to annealing, normalizing and hardening, which are conducted from the temperature of $780\pm 10^{\circ}\text{C}$ / cooling medium is oil / and tempering at the temperature of $350-420^{\circ}\text{C}$. The hardness of springs after heat treatment should be within the limits of $H_{RC} = 44-46$.

2. Alloy Steels

As it has been discussed in the previous pages, steels containing special elements / nickel, chromium, molybdenum, vanadium and others / or an increased content / against usual / of manganese and silicon are called alloyed steels. The alloying of steels changes the critical points in steel. Some alloying elements increase the critical points, while the others, on the contrary, decrease them.

The alloying elements not only improve the physical and chemical properties of steel but also facilitate the conditions of heat treatment. The alloyed steels do not require high rate of cooling at hardening. The alloying elements increase the hardenability of steel, i.e., the depth of penetration of martensitic or troostite-martensite zone of steel. Due to which fact the alloying elements increase the hardenability of steel. The alloying elements introduced into carbon steel, increase its hardenability on the account of the fact, that they retard the process of rearrangement of atoms in steel / the process of diffusion / , i.e., they decrease

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so the critical rate of hardening , and therefore the rapid cooling of heated steel in a quenching medium is not required for martensite. With alloying elements present in steel , the martensitic structure appears at greater depth of the steel part , even at slow cooling. That is why in machine parts of alloyed steel , the depth of hardening is always greater , than in the parts made of carbon steel.

Some grades of alloyed chromium-nickel steels may be cooled at hardening not in water , but also in oil or even in the air.

At tempering of alloyed steels , the phenomenon called -- the tempering brittleness , i.e. the lowering of impact ductility , takes place. Some steels , particularly chromium-nickel and chromium-manganese are very sensitive to the method of cooling after tempering. If the steel is cooled after hardening slowly / in the furnace or in the air / , it acquires considerable brittleness and the impact ductility falls sharply .

At a rapid cooling of steel in oil , the impact ductility will be higher . The other physical properties remain unchanged independently of the method of cooling, besides , the slower the cooling after tempering , the greater is the decrease of impact ductility. How the rate of cooling of chromium-nickel steel after tempering influences its impact ductility can be seen from the following comparison of values of impact ductility for one and the same steel:

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Impact ductility

kg/cm²

Slowly cooled steel after
tempering at the temperature
of 650°C

8

Rapidly cooled steel / in water/
after tempering from the same
temperature

15

The phenomenon of tempering brittleness consists in that, that the finest particles of carbides, phosphides and other components precipitate from the solid solution of iron which are disposed on planes of sliding and at the grain boundaries, thus increasing the brittleness of steel parts.

In order to avoid the tempering brittleness, the steel parts must not be tempered at a dangerous interval of temperatures / for the majority of alloyed steels this interval lies within the limits of 500-600°C/. Besides this, steels susceptible to the tempering brittleness better to cool at tempering in the air or in the oil.

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Table 9

Chemical Composition of Alloyed Steels Used for

Grade of steel	Chemical Composition, per cent				
	Carbon	Manganese	Silicon	Phosphorus	Sulphur
20 A	0.18-0.26	1.3-1.6	0.17-0.37	not over 0.35	0.035
25X CA	0.22-0.29	0.8-1.1	0.9-1.2	0.035	0.030
30X CA	0.28-0.35	0.8-1.1	0.9-1.2	0.030	0.030
50X A	0.47-0.55	0.8-0.6	0.15-0.3	0.030	0.030
12XH A	0.10-0.16	0.3-0.6	0.17-0.37	0.030	0.030
12XHB4A	0.10-0.15	0.3-0.6	0.17-0.37	0.030	0.030
18XHB A	0.14-0.21	0.25-0.55	0.17-0.37	0.030	0.030
20XHB A	0.17-0.25	0.3-0.6	0.17-0.57	0.030	0.030
38XA	0.34-0.42	0.5-0.8	0.17-0.37	0.030	0.030
40XHB A	0.26-0.44	0.5-0.8	0.17-0.37	0.030	0.030
58X A	0.35-0.42	0.3-0.6	0.17-0.37	0.030	0.030
not over					
1x18H9/ 1/	0.14	1.5	1.0	0.03	0.03
1x18H9T/ 1T/	0.14	1.5	1.0	0.03	-
not over					
100	0.15-0.3	8-10	0.8	0.03	0.03

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Table 9

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cent phorus	Sulphur	Chromium	Nickel	Other elements
over	0.035	-	-	-
.35	0.080	0.08-1.1	-	-
.025	0.080	0.08-1.1	-	-
.020	0.080	0.75-1.1		V 0.15-0.20
.030	0.030	0.6-0.9	2.75-3.25	-
.030	0.030	1.25-1.75	2.25-3.75	-
.030	0.080	1.85-1.65	4.0-4.5	W 0.8-1.2
.030	0.080	0.6-0.9	2.75-3.25	-
.030	0.080	0.6-1.1	-	Mo 0.15-0.25
.030	0.030	0.6-0.9	1.25-1.75	Mo 0.15-0.25
.030	0.030	1.85-1.65	-	Al 0.7-1.1
.03	0.03	17-20	8-11	-
.03	-	17-20	8-11	Ti 0.8
.03	0.03	12-14	3.7-5.0	-

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The heat treatment of alloyed steels differs from the heat treatment of carbon steels yet also by the following peculiarities .

The thermal conduction of alloyed steels is lesser than the thermal conduction of carbon steels. It means that alloyed steels are warmed up much slower than the carbon steels . Therefore , machine parts made of alloyed steels are subjected to a slow heating . At a fast rate of heating the surface of steel parts would have higher temperature than the core . A great difference of temperatures may lead to the development of high internal thermal stresses which may cause the appearance of cracks.

The structural transformations of alloyed steels take place at other temperatures , than in carbon steels.

For instance , the chromium steels possess the critical temperature higher than the carbon steels , and therefore the temperatures of annealing , normalizing and hardening of chromium steels must also be higher. On the contrary , the critical points of manganese and nickel steels are lower and consequently , the temperatures of annealing, normalizing and hardening of these steels must also be lower.

The chemical composition of alloyed steels most widely used for the repair of aircraft technique , is given in Table 9.

Aircraft alloy steels

Steel grade 20 / A / manganese steel /. This steel is used for the manufacture of rivets , placed in responsible structures. The steel is subjected to annealing, hardening

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and drawing. The temperature of annealing and hardening of rivets is $890 \pm 10^{\circ}\text{C}$. The quenching medium for hardening is oil. The drawing is conducted at the temperature of $600-620^{\circ}\text{C}$. The resistance of rivets to shear, made of steel grade 20 $\frac{1}{2}$ A, after hardening and drawing must be 55-70 kg/mm².

Steel grade 25 x CA is used for machine parts requiring good plasticity and proper weldability. In an annealed condition the steel permits intricate bending, knocking and stamping. This steel is subjected to normalizing, hardening and annealing. The methods of its heat treatment are shown in Table 10.

Table 10

Methods of heat treatment of steel grade 25x CA				
Temperatures of normalizing, hardening and annealing $^{\circ}\text{C}$	Quenching medium	Drawing temperature $^{\circ}\text{C}$	Hardness	Tensile strength σ_B kg/mm ²
890 $\pm$ 10	oil	620-640	20-27	70-90
890 $\pm$ 10	oil	520-540	27-35	90-110
890 $\pm$ 10	oil	490-510	33-37	100-120

The time of holding of steel at hardening and drawing is chosen depending on the part's shape and its thickness, as has been indicated in the previous pages/page 86-90/.

Steel grade 30x CA / chromansil/. This steel is rather widely applied in the aircraft building and used for the manufacture of complex parts, either welded or machined / bolts, chassis' parts, jointing connections,

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flanges, racks, etc./

This steel is subjected to hardening, annealing and normalizing.

The methods of heat treatment of this steel are given in Table 11.

Table 11.

Methods of Heat Treatment of Steel Grade 30X1CA

Temperature of hardening, annealing and normalizing °C	Quenching medium	Drawing temperature	Hardness	Tensile strength B kg/mm ²
880±10	oil	660-680	19-28	70-90
880±10	oil	620-640	23-30	80-100
880±10	oil	580-600	28-35	90-110
880±10	oil	540-560	30-37	100-120
880±10	oil	520-540	35-39	110-130
880 ± 10	oil	480-500	37-44	120-140

All machine parts made of steel grade 30X1CA, at the beginning are subjected to hardening from the temperature 880±10°C in the oil, and then to drawing. The drawing temperature is selected depending on the required properties of steel.

For instance, for clamp bolts and jointing assembly units, made of steel grade 30X1CA the tensile strength is required within the limits of 110-130 kg/mm² or 130-140 kg/mm², that corresponds to the hardness of HRC 35-39 and 37-44. Consequently, in order to obtain the required tensile strength /B/ it is necessary to choose the drawing temperature of 520-540°C or correspon-

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dingly 480-550°C

Generally, power bolts are made of normalized rods of steel grade 30X/CA. If the steel rods are subjected to hardening then it is necessary to normalize them, i.e., to heat to the temperature $880 \pm 10^\circ\text{C}$, hold them at this temperature in accordance with their diameter and then cool them in the air.

The manufactured steel bolts are subjected to hardening from a temperature of $880 \pm 10^\circ\text{C}$ in the oil / the temperature of the oil should be 20-70°C/.

The bolts should be put into the furnace in one row, inasmuch as if they are put in two or more rows, the bolts may not be warmed through and the hardening would be incomplete. The time of holding of the bolts in the furnace is determined according to table 12.

Table 12

Time of Holding

of bolts made of steel grade 30X/CA for hardening, depending on their diameter.

Diameter of bolts in mm	4	6	8	10	12	14	16
Time of holding for hardening in minutes	7	9	11	13	15	17	19

Note. The time of holding at hardening is considered from the moment of reaching the required temperature in the furnace.

Spindle oil M3 or transformer oil is used for hardening of steel bolts.

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After hardening the bolts are subjected to drawing. The drawing temperature is selected from Table 11, depending on the required properties of steel.

The time of holding of steel bolts at drawing is chosen from Table 13 depending on the bolts diameter and the drawing temperature. The lower the drawing temperature, the greater is the holding.

Table 13

Time of holding

of steel bolts at drawing, depending on their diameter

Bolts diameter in mm	4	6	8	10	12	14	16
Time of holding in minutes							
Time of holding at temperature up to 300°C	124	126	128	130	132	134	136
Time of holding at temperature 300-400°C	24	26	28	30	32	34	36
Time of holding at temperature above 400°C	14	16	18	20	22	24	26

Note . The time of holding of steel bolts at drawing is counted from the moment of reaching the required temperature in the heating furnace.

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The bolts, both at hardening and drawing are charged into the heating furnace only when it is warmed up to the required temperature.

The steel bolts, and also other machine parts made of steel grade 30X/CA are cooled after drawing only in the air or in the oil. The cooling of bolts together with the heating furnace is absolutely forbidden in order to avoid the appearance of tempering brittleness.

After heat treatment, the steel bolts are subjected to testing inspection for hardness using the testing machine TK- / scale HA/ and by the reference tables printed at the end of this book. At this testing the tensile strength of steel bolts is verified. If the steel bolts were obtained with an increased hardness, the remedy is the repeated drawing at much higher temperatures. If the steel bolts were obtained with a decreased hardness, then they may be subjected to the repeated hardening with consequent drawing at much lower temperature, than it was applied at the first drawing. / but not lower than 450°C/.

Steel grade 30X/CHA / see table 2/ is used in the same way as the steel 30X/CA, but for the manufacture of the most important steel parts of the airplane. To secure a better mechanical workability of this steel, the following method of heat treatment is recommended: normalizing from a temperature of 900°C with a consequent accelerated annealing / heating up to the temperature of 780°C, holding at this temperature till complete warming up of

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the steel part ; cooling together with the furnace to 600°C , holding at a temperature of 600°C for 1.5-2.0 hours and further cooling in the air/.

Hardening of steel parts made of steel grade 30X¹ CHA is conducted from a temperature of $890^{\circ}\text{C} \pm 10^{\circ}\text{C}$ in oil , drawing at a temperature of $200-300^{\circ}\text{C}$, holding the steel parts at this temperature for not^{less}/than 2 hours.

Steel grade 50X¹ A is used for the manufacture of main springs. The springs are subjected to hardening and drawing. The hardening of springs made of steel wire grade 50X¹ A is conducted from a temperature of $850 \pm 10^{\circ}\text{C}$ in oil / annealing and normalizing of this steel is conducted at the same temperature/ , while the drawing is conducted at a temperature of $370-460^{\circ}\text{C}$ with holding in the heating furnace for 30-45 minutes: if the drawing is conducted in a salt bath and not in the furnace , then the holding of steel parts should be 10 minutes. The hardness of heat treated springs made of steel grade 50X¹ A lies within the limits of $HRC = 42-50$.

Alloy steels for Aircraft Engine Parts

Steel grade 18XH3A is used for the manufacture of parts for aircraft engines : gears , piston pins, distributing and other shafts , adjusting screws , etc. As a rule , the aircraft parts made of this steel are subjected to case-hardening. Prior to the case-hardening , the steel is subjected to a preliminary heat treatment - normalizing at a temperature of $840-880^{\circ}\text{C}$. Case-hardening is accomplished at a temperature of $900-920^{\circ}\text{C}$. Fol-
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lowing casehardening the steel is subjected to a final heat treatment : hardening from a temperature of 800°C by quenching in oil , then again hardening from a temperature of 780-810°C by quenching in the oil and finally the steel is tempered at a temperature of 150-170°C for a period of 3 hours.

Steel grade 12X2H4A is used for the manufacture of main gears: satellite reduction gears , double timing gears , elastic transmission gears , driving and driven gears , and also for shafts , piston pins, etc. This steel may be substituted by steel grade 12XH3A.

Steel grade 12X2H4A is referred to the casehardening class of steels. Its heat treatment is similar to that of steel grade 12XH3A.

Steel grade 18XHBA is used for the manufacture of crankshafts , reductor shafts , gears , connecting rods , main bolts and pins.

The steel is referred to the casehardening class of steels. Its casehardening is accomplished at a temperature of 900-920°C. After casehardening steel grade 18XHBA is finally heat treated by one of the following methods:

1. Hardening from a temperature of 950°C with cooling in the air , then repeated hardening from a temperature of 850-860°C with cooling in the air and tempering at a temperature of 150-170°C. The hardness acquired by steel after such heat treatment should be $HRC = 37-41$.

2. Hardening from a temperature of 860-870°C with cooling in the air , tempering at a temperature of 150-170°C. The hardness acquired by this steel after such heat treatment should be $HRC = 36-41$.

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8. Hardening from a temperature of $860-870^{\circ}\text{C}$ with cooling in oil , drawing at a temperature of $525-575^{\circ}\text{C}$ with consequent cooling in oil.

The hardness acquired by the steel after such heat treatment should be $HRC = 34-41$. In steel grade 18XHBA, the tungsten is often substituted by molybdenum and then the steel is marked as grade 18XHMA steel.

Steel grade 20XH2A is used for the manufacture of bolts, pins, bushings, gears, shafts, etc. It is recommended to substitute this steel by steel grade 38XA, inasmuch as this steel is not inferior to steel grade 20XH3A as for its physical properties , but is considerably cheaper, since it does not contain the expensive nickel.

Steel grade 20XH3A is subjected, at the beginning, to a preliminary heat treatment -- to annealing at a temperature of 800°C , or to drawing at a temperature of $650-680^{\circ}\text{C}$, and then is subjected to the final heat treatment-- to hardening from a temperature of $820-840^{\circ}\text{C}$ in oil or warm water and to drawing at a temperature of $400-500^{\circ}\text{C}$ with cooling in oil or in warm water. The hardness after hardening and drawing should be $HRC = 32-37$.

Steel grade 38XA / chromium steel/ is used for the manufacture of gears , bolts , pins, nuts , screw bushings, etc. This steel is widely used by the auxiliary units of Air Forces for the manufacture of bolts and main pins for aircraft repair.

Steel grade 38XA is subjected to hardening and drawing. The method of heat treatment of this steel is shown in Table 14.

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Table 14

Temperature of hardening and drawing of steel parts made of steel grade 38XA.

Hardening temperature °C	Quenching medium	Drawing temperature °C	Hardness	Tensile Strength kg/mm ²
860±10	oil	640-660	18-26	70-90
860±10	oil	580-600	26-34	90-110
860±10	oil	540-560	30-37	100-120
860±10	oil	500-520	34-40	110-130

The time of holding at heating for hardening and for drawing is determined according to the tables 5 and 6. The time of holding for bolts and pins made of steel grade 38XA is the same as for bolts made of steel grade 30X CA, therefore the time of holding at hardening and drawing of bolts made of steel grade 38XA can be determined according to the tables 12 and 13. / See pages 100-101/.

Steel grade 40XHMA is used for the manufacture of crankshafts, airscrew shafts, connecting rods, main bolts, pins, airscrew parts, etc. At the beginning this steel is subjected to a preliminary heat treatment - annealing at a temperature of 840-880 °C or to drawing at a temperature of 650-680 °C and then to a final heat treatment - hardening from a temperature of 850 °C in oil and to drawing for the required hardness. Fig.35 shows the dependence

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of physical properties of this steel on the temperature of drawing. The time of holding at hardening and drawing of bolts and pins is the same as for the steels of grades 30X¹CA and 38XA.

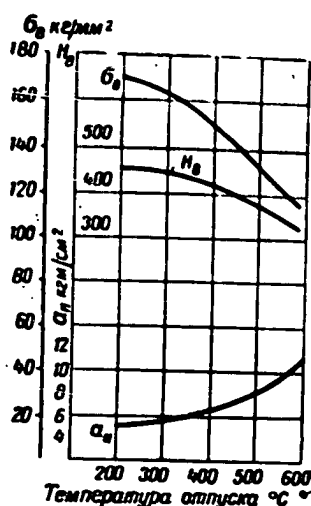


Fig. 35. Dependence of physical properties of steel grade 40XHM1A on the temperature of drawing.
1/ Temperature of drawing °C; 2/ σ_B , kg/mm²; 3/ σ_T , kg/cm².

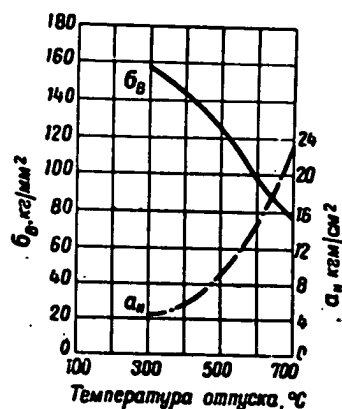


Fig. 36. Dependence of physical properties of steel grade 38XMA on the temperature of drawing.
1/ Temperature of drawing °C; 2/ σ_B , kg/cm²; 3/ σ_T , kg/mm².

Steel grade 38XMH is the steel subjected to nitriding, and is used for the manufacture of gears, cases, shafts, rollers, and other steel parts subjected to nitriding. At the beginning, this steel is subjected to a preliminary heat treatment -- annealing at a temperature of 930°C or to drawing at a temperature of 650-680°C, and then to a final heat treatment-hardening from a temperature 2074

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of 930-950°C in warm oil, and to the drawing at a temperature of 600-670°C with a consequent cooling in oil or water. The influence of the drawing temperature upon the physical properties of steel grade 3X18H9A is shown in Fig. 26.

Particularities of Heat Treatment of an Austenite Class of Steels Grades 1X18H9 /Q1/ and 1X18H9T /Q1/.

Steel grades 1X18H9 /Q1/ and 1X18H9T /Q1/ differ from other alloyed structural steels in that, that at cooling from high temperatures, they retain the structure of austenite till the usual room temperature, besides, the faster the rate of cooling, the better plasticity this steel obtains. On the contrary, drawing of steel grade 1X18H9T with heating to a temperature of 600-700°C leads to an appreciable increase of hardness, whereas the drawing of other / non austenite class / steels from the same temperature is always connected with a decrease of hardness and strength of steels.

In this way, the results of hardening, and also of drawing of austenite steels are directly opposite to those results which are obtained at hardening and also at drawing of carbon and alloyed structural steels.

Steel grade 1X18H9 /Q1/ is austenite chromium - nickel steel; it is referred to the class of stainless acid resisting steels. This steel is used for the manufacture of jet aircraft engine and airplane parts, situated near hot gasses, and heated to the temperature of

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500°C. Steel grade 1X18H9 is also used for machine parts / in hardened condition / , subjected to the action of nitric acid.

The method of heat treatment of this steel is as follows : hardening from a temperature of 1100-1150°C in water or in an air jet , holding at this temperature for 5-10 minutes.

Steel grade 1X18H9T / 1T/ is austenitic chromium steel with titanium . It is used in the aircraft building for exhaust connections , collecting manifolds, mufflers, nozzles and for gas turbocompressors, welded apparatus and parts subjected to the action of nitric acid of all concentrations.

The methods of heat treatment of this steel is as follows : hardening from a temperature of 1100-1150°C in water. The steel is welded easily by all types of welding.

Steel grade 1X18H10 is chromium-nickel-manganese steel. It is used for the manufacture of some aircraft parts and armaments. It can be easily welded by oxy-acetylene and arc welding.

The method of heat treatment of this steel--hardening from a temperature of 1120-1150°C in water or in a jet of compressed air.

Chapter XI

Thermo-chemical Treatment of Steel

1. Casehardening

Casehardening is a process of carburization, through the penetration of carbon into the surface layer of steel articles.

At this process, the surface layer of steel article is enriched with carbon. This makes a basic difference of casehardening from other methods of heat treatment described above.

The casehardening has its purpose to increase the hardness of outside layer of machine parts made of tough steel. The hard surface of steel resists better to wear at friction, while a tough core increases the durability of the machine part under the action of impact loads.

The strengthening of steel by a process of cementation found its application in the late eighties of the last century. Up till now it has been thought that the inventors of this process were the German Krupp and the American Harvey. However, recently it was definitely established, that the priority in this case belongs to Russia. The Russian metallurgist Vasily Piatow, 25-30 years before Krupp and Harvey, proposed the process of cementation of armour plates by the method, which remains almost unchanged up to the present time.

Fig. 37 shows gear's teeth after casehardening. The dark edging of the teeth presents a case hardened layer.

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Fig.27. Structure of case hardened gear's teeth.

The hardness of the carburized layer is not inferior to the hardness of the tool steel , whereas , the core of the gear's tooth retains the necessary toughness.

The process of casehardening is based on the ability of carbon to penetrate the solid iron or steel at high temperature .

As a cementizing matter , the so--called carburizers are used , which contain one or another kind of carbon .

The carburizer may be as a powder /solid/ , in a form of a paste / liquid / and as a mixture of gases / gaseous/

The solid carburizer consists of a powdered charcoal with addition of different carbonates , accelerating the process of carburizing. Barium carbonate / 20-25 per cent by weight / is often used as such addition.

The most widespread composition of solid carburizers is indicated in Table 15.

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Table 18

Composition of Solid Carburizers / per cent/

Grade	Baco	CaCO_3	SiO_2	S	Volatiles composition per cent	Moisture maximum, per cent
	Maximum			minimum		
A	20-25	3.5	0.5	0.06	3.0	5
B	20-25	5.0	1.5	0.10	Not limited	5

The liquid carburizer / paste , containing charcoal , soluble glass and carbonates / is spread over the machine part with a brush or the part is dipped into the carburizing solution. The parts, prepared in such a way , are quickly packed into a carburizing box and are heated to a carburizing temperature . The layer of paste 3-4 thick secures the depth of carburization up to 1 mm.

Recently , the gaseous carburizers supplanted the carburizers described above , and are broadly introduced into industrial practices. The following gases , containing carbon monoxide and hydrocarbons , are used for carburizing : methane / CH_4 / , ethane / C_2H_6 / , propane / $\text{CH}_3\text{CH}_2\text{CH}_3$ / and butane / C_4H_{10} / . The composition of gaseous carburizing medium inevitably includes inert gases , such as nitrogen and active decarburizing gases--hydrogen , carbon dioxide and water steam. The content of carbon dioxide, hydrogen and water steam must be at minimum.

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Steels Subjected to Casehardening

The casehardening may be applied to carbon steels containing from 0.05 up to 0.25 per cent of carbon. Steels containing *higher* per cent of carbon cannot be subjected to casehardening inasmuch as , after carburizing , they become brittle.

The casehardening may also be applied to alloy steels, containing chromium , nickel , molybdenum and tungsten, for instance , steel grades 12XH3A and 18XHBA. Machine parts, manufactured of these steels / gears, crankshafts, camshafts, piston pins/ may be successfully subjected to casehardening.

Casehardening with solid carburizer

Prior to casehardening , the machine parts must be thoroughly cleaned of dirt , rust and greases, which hamper the carburization of steel. All parts of steel articles, not subjected to casehardening , are protected by coating with an electrolytic layer of copper 0.005mm thick . The openings in the article are filled with fireclay.

After cleaning , steel articles are placed into a box made of heat resisting alloy ^{1/} , on the bottom of which there ~~is~~ is a layer of carburizer 40-50 mm thick. The articles must not touch each other . The distance between them

1/ Welded steel boxes made of sheets 6-8 mm thick may be used for casehardening. But in the latter case the boxes are subjected to alitizing. / The process of surface impregnation with aluminium /.

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should equal 10-15 mm. The space between the walls of the box and the articles must be 20-25 mm. After laying of one row of articles, they are covered with carburizer / thickness of strewing is 25-30 mm/, then the carburizer is lightly rammed. New rows of articles are placed in the carburizing box in the same manner. A layer of rammed carburizer 40 to 50 mm thick must be provided between the box cover and the upper row of articles.

After the packing of articles is completed, the carburizing box is closed with a flanged cover and is coated with a mixture of fire clay and sand.

The boxes are put into a furnace, heated to a temperature of 300-400°C, then the furnace is heated up to 700°C. The heating must be conducted slowly since at fast heating the gases may force their way through the box joints.

To control the depth of casehardening, 2 pins, the so called "witnesses" are put into the carburizing box with their ends protruding outside. One of the pins is taken out one hour before the end of the process and another one 10-15 minutes before the end. By examining of the pin's fracture, the depth of the casehardening is determined.

After cooling, the articles are taken out of the box and are subjected to the following heat treating process:

1. Normalizing from temperature of 900 to 920°C for elimination of coarse-grain structure of the core.

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2. Hardening from temperature of 750 to 760°C for elimination of overheating of carburized layer and imparting to it the required hardness.

3. Tempering at temperature of 150-170°C for removing of inner stresses .

Gas Casehardening

The advantage of gas casehardening in comparison with case hardening in a solid carburizer is as follows:

1. At gas casehardening it is easy to obtain the required depth of carburized layer and the desirable distribution of carbon , owing to which it is possible to regulate the temperature , the pressure of the process and the composition of carburizing gas.

2. The time required for gas case hardening is three times less , than that required for casehardening in solid carburizer.

3. There is a possibility to mechanize fully the process of carburizing.

4. The required area of the furnace bottom on which the process is conducted , can be decreased by two times.

The gas casehardening of small steel articles may be performed in the muffle electric furnace M₂-2 , for which purpose it must be hermetically sealed.

Steel articles , subjected to gas casehardening are placed into the furnace / or into the steel box which is then set into the furnace /, after that the gas is introduced into the carburizing furnace. The temperature is raised to the temperature of casehardening of 900-980°C

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The duration of the casehardening process depends on the depth of carburizing layer. Since, for the majority of casehardened steel articles / gears, camshafts, etc/ the depth of the carburized layer lies within the limits of 0.5 to 1.5 mm, the time of the process should be 2 - 3 hours. After this holding, it is necessary to cool the steel articles in the same furnace to the temperature of 820-760°C / during 10-15 minutes /. If the steel article is cooled to the temperature below 760°C, then its core obtains coarse-grained structure and due to this the toughness of steel considerably lowers. The further cooling can be performed in water or oil / depending on the grade of steel /.

To remove the inner stresses the case hardened steel articles are subjected to low tempering / 170-190°C /.

The hardness of the surface carburized layer, after such heat treating process, should be above

$H_{RC} = 55$.

2. Nitriding of Steel

The nitriding is a process of impregnation of steel article's surface with nitrogen.

The nitriding has the following purpose : to increase the hardness and wear resistance of the upper layer of steel articles, to rise the fatigue limit of steel, and also to increase the corrosion resistance of steel in atmosphere, fresh water, superheated steam, etc.

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The efficiency of nitriding has been proved by an extensive period of exploitation of aircraft engines with nitrided steel parts / cylinder liners , valves , gears , crankshafts of engines , etc. /.

The Russian scientist academician N.P. Tchijevsky who from 1907 to 1914 published 14 scientific papers on the influence of nitrogen on iron and some other metals , is rightfully considered the founder of the nitriding process. In 1922-1923 the nitriding process began to be used on an industrial scale.

The wide application of nitriding process in machine-building was facilitated to a great degree , by the researches of the Soviet scientists N.A. Minkevitch, I.A. Lechtin, L.E. Kontorowitch , V.I. Prosvirin , S.A. Yuriev and others .

A considerable quantity of nitrogen may be absorbed by steel surface only in case when it is in the atomic state and is the product of disintegration of nitrogenous compounds in whose atmosphere the nitriding process takes place.

An ammonia / NH_3 / is used for the nitriding process , which at the contact with the metal surface disintegrates , evolving atomic nitrogen , which due to its activity penetrates the crystalline space lattice of steel.

All alloying elements , and particularly aluminum, increase the hardness of the nitrided layer of steel.

Nickel does not form nitrides and therefore its influence

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on the hardness of nitrided steel layer is almost negligible.

As it has been explained by scientists , the increase of hardness at nitriding under the influence of alloying elements is due to the formation of the finest nitrides, which strengthen the planes of sliding and distort the crystalline space lattice of steel .

The nitriding of steel articles includes the following operations:

1. A preliminary heat treatment which imparts to steel a necessary complex of physical properties .
2. Mechanical working of a steel article , including a rough grinding.
3. Protection of places not subjected to nitriding.
4. Impregnation of steel surface with nitrogen.
5. Finish grinding or final sizing in accordance with stipulated tolerances.

The nitriding of small steel articles may be conducted in a muffle furnace M7-2. For this treatment , the articles are placed into an unheated furnace and then the furnace is heated to the required temperature with with articles in a stream of ammonia , which is supplied into the furnace from a gas cylinder . The process of nitriding is performed at temperatures of 490-560°C; the duration of process is from 8 to 90 hours .

To facilitate the nitriding process , a combination of thermal treatment / double cycle / is used . At the beginning, the nitriding is conducted at a temperature of

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500-520°C , then the temperature is raised up to 600-620°C. For the intensification of the process of nitriding the aniline is introduced into the furnace.

The nitrided steel articles are subjected to control for hardness of the surface layer , depth of the intrided layer and its brittleness.

The hardness of the nitrided layer is checked by the hardness device TK-1 at loading of 15, 30 and 60 kg.

The depth of the nitrided case is checked by examining of microstructure of a cut and etched control specimen. It is etched by the mixture of 4% nitric acid and 4% picric acid in relation of 10:12. After etching the nitrided layer has a dark colour.

The brittleness of the nitrided layer is determined by examination of indentation after hardness testing with a diamond cone. If the edges of indentation made by the diamond cone are strikingly crumbled , then the nitriding process was performed unsatisfactory.

3. Alitizing of Steel

At present time many parts of an aircraft engine are made of heat resisting alloys. A considerable content of chromium , nickel and other alloying elements make these alloy steels less subjected to destructive action of high temperatures - gas corrosion. However , the above steels are scarce and 15-20 times more expensive than the regular carbon steels. Therefore , the search for inexpensive methods of protection of regular carbon steels against gas corrosion at high temperatures has a great importance. In

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this respect an important place belongs to the process of alitizing. The alitizing is a process of impregnation of an upper steel layer with aluminum, which imparts the steel a necessary resistance against oxidation at high temperatures.

Steels with low carbon content are alitized satisfactorily. The resistance against gas corrosion of articles made of carbon steel, and operating at an interval of temperatures 700-850°C, after alitizing increases about 20 times.

To provide quick and uniform alitizing, the surface of the steel articles must be thoroughly cleaned of rust and grease, inasmuch as they delay the process of diffusion. This is done either mechanically or by a chemical method.

Articles made of alloy steel, yield to alitizing unsatisfactory.

The process of alitizing is simple and does not require complicated equipment and may be accomplished in any heat treating shop.

The impregnation of steel articles with aluminum is conducted at high temperatures. Mixtures, consisting of aluminum, alumine and sal ammoniac NH_4Cl are used for alitizing. Sometimes, an iron-aluminum alloy is introduced into the mixture instead of aluminum.

The following mixtures acquired a wide application for this process:

No.1. Iron-aluminum alloy	99.5 per cent
Sal ammoniac :	0.5 per cent
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No.2. Iron-aluminum-copper alloy

48% Al , 3.6% Cu 99.5 per cent

Sal ammoniac 0.5 per cent

No.3. Metallic aluminum 49 per cent

Alumina 49 per cent

Sal ammoniac 2 per cent

The above mentioned mixtures , and also many other mixtures in the form of powders , are available on the market.

The process of alitizing is performed as follows: The sal ammoniac , present in the mixture , decomposes under the action of high temperatures into ammonia and hydrogen chloride / HCl / and aluminum chloride / $AlCl_3$ / is formed, which interacting with iron yields at high temperatures gaseous iron chloride and atomic aluminum.

The atomic aluminum diffuses into steel.

The depth of the alitizing layer depends on the temperature of heating , the duration of the process of alitizing , the composition of the mixture , the condition of the article's surface and the carbon content in the basic metal.

The higher the temperature , and the longer the period of the alitizing process , the greater is the depth of the alitizing layer in the article .

The regimes of alitizing of steel articles of different thickness are given in Table 16.

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Table 16Regimes of alitizing process for steel articles

Articles	Mixture number	Temperature, °C	Duration of alitizing, in hours	Depth of alitizing layer, mm
Thin walled steel	1;2	850	3	0.08
Thin walled steel	1;2	850	6	0.14
D i t t o	1;2	900	3	0.09-0.12
D i t t o	1;2	900	6	0.15-0.19
Thick walled steel articles	1;2;3	975	3	0.13-0.15
D i t t o	1;2;3	975	6	0.20-0.32
D i t t o	1;2;3	1050	3	0.30-0.38
D i t t o	1;2;3	1050	6	0.40-0.58

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Chapter VII

HEAT TREATMENT OF TOOLS

In this chapter , we discuss briefly particularities and properties of steels , used for the manufacture of tools and then acquaint the reader with methods of heat treatment of different tools.

It is necessary to note that not every tool may be subjected to heat treatment in conditions of military repair. Tools , made of high speed tool steels and hard alloys require the temperature of heating up to 1150-1300°C, therefore they cannot be subjected to heat treatment in the furnace M77 -2 type , since the working temperature of this furnace does not exceed 1000°C.

However , in practical operations of service of aircraft technique , the technical personnel makes use of different tools and devices made of carbon and alloy tool steels ; the temperature of heat treatment of those tools does not exceed 1000°C. The tools made of these steels may and must be subjected to heat treatment in conditions of military repair of aircraft technique.

1. Steels used for the manufacture of tools.

As a rule , tool steels are used for the manufacture of tools.

All tool steels are divided into the following four categories:

1. Carbon tool steels .
2. Alloy tool steels.

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3. Die steels

4. High speed tool steels .

Carbon and alloy tool steels are used for the manufacture of cutting tools , utilized for relatively light conditions of operating , and also for the manufacture of measuring instruments.

Die steels are employed for the manufacture of dies. High speed tool steels are used for making of cutting tools operating at high cutting speeds.

Tools used for extra high cutting speeds are made of hard and extra hard alloys.

For the two last decades , the Soviet science of metals has solved many complicated problems of alloying and heat treatment of tool steels. The modern methods of heat treatment applied in the tool making industry have been worked out by Soviet scientists before it had been done abroad. To these methods are related : step-down hardening , multiple tempering , treatment with cold, high frequency current heating , low temperature cyaniding and others .

Our scientists evolved very valuable grades of tool steels and alloys , and worked onto proper methods of tool steel strengthening by a corresponding heat treatment.

Carbon Tool Steels

The chemical composition of carbon tool steels applicable for making of cutting and measuring tools is indicated in Table 17.

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Table 17

Chemical Composition of Carbon Tool Steels					
Grade	Chemical Composition, per cent				
	Steel Carbon	Manganese	Silicon	Sulphur	Phosphorus
			Maximum		
Y7A	0.60-0.74	0.25-0.35	0.30	0.030	0.030
Y8A	0.75-0.84	0.25-0.35	0.30	0.020	0.030
Y9A	0.85-0.94	0.20-0.30	0.30	0.020	0.030
Y10	0.95-1.09	0.15-0.25	0.30	0.020	0.030
Y12	1.10-1.25	0.15-0.25	0.30	0.020	0.030
Y13	1.26-1.40	0.25-0.35	0.30	0.020	0.030

An exemplary application of carbon tool steels is reported in Table 17, is given below.

Steel grade Y7A is used for the manufacture of tools with a necessary toughness at a moderate hardness, subjected to shocks, for instance, chisels, stamps, forging tools.

Steel grade Y8A is used for the manufacture of tools with good toughness at high hardness, subjected to shocks, for instance cutting shears, knives for metal, carpenter and pneumatic tools.

Steel grades Y9A and Y10 are used for making of tools with maximum hardness on the cutting edge, not subjected to severe blows, for instance: drills, taps, reamers, cutters, milling cutters and others.

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Steel grades Y12 and Y13 are used for the manufacture of tools with a maximum wear resistance at highest hardness, for instance: cutters, different metal cutting tools and measuring instruments, files, chisels for cutting of files and for other tools and instruments.

It is evident from the above characteristic and application of carbon tool steels, that the property of steel and its application depend on the carbon content.

Methods of heat treatment also depend on the percentage of carbon, contained in steel.

The temperatures of hardening and tempering of tools made of carbon tool steels are indicated in table 18 below.

Table 18

Temperatures of hardening and tempering for some tools made of carbon tool steels.

Kinds of tools	Grade of Steel	Hardening temperature °C	Tempering temperature °C	Hardness of the working part
Chisels	Y9A	800-830	280-300	56-58
Chisels	Y9A	790-820	260-280	56-60
Taps	Y12	770-790	180-200	60-62
Threading dies	Y10	780-800	220-240	59-61
Reamers	Y10	780-800	160-180	62-64
Dies for cold stamping	Y10	780-800	200-220	60-62

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After hardening , steel grades Y7A , Y8A and Y9A acquire the microstructure of martensite , while steel grades Y10, Y12 and Y13 possess the microstructure of martensite plus cementite .

Owing to quick transformation of austenite at the temperature interval of 500-600°C, the tools made of carbon steel must be quenched in water . At this treatment only surface layer is hardened, while the core remains non-hardened , soft. Following such treatment the tools are less brittle , withstand blows easier than the tools made of steel with hardness through. In practice, the following should be borne in mind. At rough grinding of tools made of carbon steel, the surface hardened layer is removed , and non-hardened parts of steel appear. This condition requires repeated heat treatment of tools.

Alloy Tool Steels

Small additions of tungsten , vanadium , silicon or manganese to high carbon steel improve its properties , make this steel non-susceptible to overheating , impart the steel much higher hardness and resistance to wear.

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Table 19

Chemical Composition of Alloy Tool Steels

Grade of steel	Chemical Composition, per cent						
	Carbon	Manga- nese	Sili- con maximum	Chro- mium	Tungs- ten	Vana- dium	Nickel maxi- mum
B1	1.05-1.25 0.20-0.40		0.35	0.1-0.3	0.8-1.2	0.15-0.30	0.3
B2	1.10-1.25 0.20-0.40		0.35	0.1-0.3	1.6-2.2	-	0.3
	0.95-1.05 0.20-0.40		0.35	-	-	0.20-0.40	0.3
X05	0.25-1.40 0.20-0.40		0.20-0.25	0.4-0.6	-	-	0.25
X	0.95-1.10	0.40	0.35	1.3-1.6	-	-	0.25
9X	0.60-0.95 0.25-0.35		0.25-0.45	1.4-1.7	-	-	0.3
9X	0.85-0.95 0.30-0.60		1.20-1.60	0.95-1.25	-	-	0.3
X ⁿ	1.20-1.50 0.45-0.70		0.35	1.2-1.6	-	-	0.25
XB ⁿ	0.9-1.05 0.60-1.10		0.15-0.35	0.9-1.20	1.2-1.4	-	0.3
XB5	1.25-1.50	0.30	0.30	0.4-0.7	4.5-5.5	-	0.25

The exemplary application of alloy tool steels is given below.

Steel grade B1 is used for the manufacture of helical drills, taps, threading dies, knives, etc.

Steel grade B2 is utilized for making of knife blades for cutting of metal.

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Steel grade ^{tool} is applied in the same cases as steel grade B1 and carbon/steels Y10 and Y12. Owing to an increased toughness, in addition to the above mentioned purposes this steel is utilized for making of percussion tools for production of bolts, nuts and rivets.

Steel grade X05 is used in the same cases as carbon tool steels grades Y12 and Y13, this steel gives no defects characteristic for the carbon tool steel, such as soft spots on the surface at hardening.

Steel grade X is used for the manufacture of tools from which, high hardness and wear-resistance at deep hardenability and low deformation at hardening, are required. Cutters, milling cutters, chisels for cutting of files, are made of this steel.

Steel grade 9X is utilized for the same purpose, as steel grade-X.

Steel grade 9XC is used for making of drills, reamers, taps and threading dies.

Steel grades X and XB are utilized for the manufacture of tools, which are to possess a minimum deformation at hardening.

Steel grade XB5 is used for the manufacture of finishing tools / turning, planing and grooving cutters and milling cutters and also for tools used for machining of hard materials / hardened steel, white cast iron /.

Heat treatment of the above mentioned steels is stipulated in Table 20.

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Table 20Heat Treatment of alloy tool steels

Grade of steel	Temper- ature of anneal- ing ° C	Harden- ing tempera- ture ° C	Quench- ing medium for harden- ing	Hardness after heat treatment	Tempering temperatu- re °C
B1	750-770	790-810	Water	65-67	150-170
B2	780-800	770-790	ditto	65-67	150-170
	740-780	790-810	ditto	62-65	150-170
D5	770-790	780-800	ditto	62-65	150-250
X	770-790	780-800	ditto	64-66	150-250
9X	770-790	820-840	oil	62-64	150-250
X	770-790	780-800	water	64-66	150-250
X	770-790	820-840	oil	62-64	150-250
9XC	780-810	850-870	ditto	62-64	150-200
X	790-810	820-850	ditto	62-64	160-220
XB	770-790	820-850	ditto	63-65	160-220
XB5	800-820	800-820	water	65-67	120-150
XB5	800-820	850-870	oil	62-69	

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2. Heat Treatment of Tools

Heat treatment of a chisel

The locksmith's chisel, utilized for cutting of metal, is made of carbon tool steel Y7A, Y8A or Y9A.

Heat treatment of a steel chisel includes hardening with a following drawing at the expense of chisel's heat.

For heat treatment the chisel is placed into the furnace M-2, heated to a hardening temperature / see table 18/. At the first moment the furnace temperature would drop by 15-30°C.

After the furnace temperature reaches again the necessary minimum, the time of holding is recorded. It must be within the limits of 20-25 minutes.

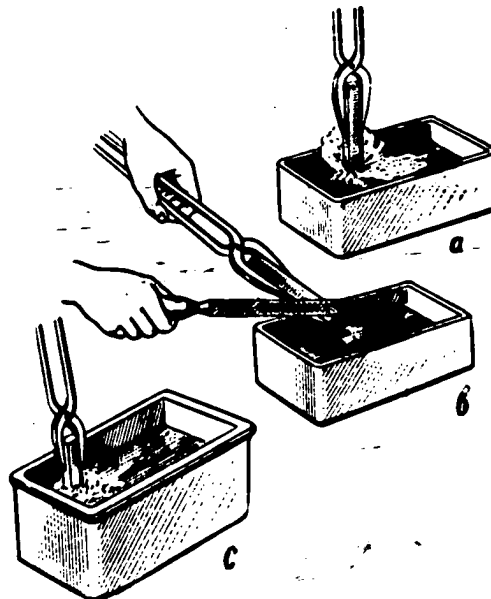


Fig.38. Methods of submerging the chisel at heat treatment operations :
a/ submergence into water tank ; b/ cleaning of chisel ; c/ final cooling .

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After the end of the holding period, the chisel is taken out of the furnace with tongs, and its working part / but not the whole chisel / is submerged vertically into the quenching tank with water. / Fig.38/.

In order to avoid a sharp difference of structure between hardened and non-hardened parts of the chisel, the latter is moved up and down by 1-2 cm, while it is held in the water. As soon as the working part of the chisel darkens, the chisel is quickly taken out of the water, its blade is cleaned with a file, emery paper or a stone, and tempered. The tempering is conducted until a cornflower-blue colour of tempering appears on the chisel. As soon as such colour appears on the chisel's blade, the chisel is dipped into the water or oil until the cooling is completed.

After hardening, the chisel is necessary to test at operation. If the chisel's blade is crumpled, then it is necessary to harden the chisel anew and temper it at a much lower temperature until violet colour of tempering appears.

If the chisel's blade at testing is crushed, it means the hardening was too "dry". Then it is necessary to repeat the hardening, and temper the steel chisel at a much higher temperature, until the light blue colour of tempering appears.

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Heat treatment of taps

Taps are made of carbon tool steel grade Y12 , and also of alloy tool steel grades X¹ , XB¹ , B1 and 9XC. The heat treatment of taps is performed in such a way as to impart to them only the surface hardening , leaving the core of the taps unhardened. This is necessary in order to have the tap sufficiently tough and that it could easily withstand high stresses of torsion , which are developed at operations . Besides that, the dimensions of the tap and its pitch of threading remain more precise and change very little at surface hardening .

For hardening , the tap is placed into the furnace M/1 -2 , heated to the hardening temperature / see table 18/ and is held there a necessary time. In order to provide the hardening of the surface layer of the tap only, the holding time of this operation must be at minimum. As soon as the colour of the tap's surface equalizes with the colour of the inner walls of the heating furnace , the tap must quickly be withdrawn and quenched in water or oil. To prevent a sharp warpage , the tap is submerged into the quenching liquid vertically . / See Fig. 39/.

In order to avoid the decarburization and oxidation of the tap's surface during its heating , a small amount of charcoal is added into the furnace M/1 -2. The tempering of the tap is carried out by a repeated heating in the

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furnace M¹-2 up to 160-200°C ; the time of holding of the tap at tempering must be 1-1.5 hours.

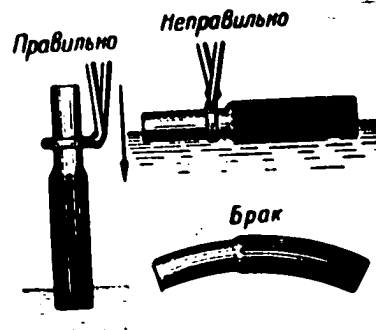


Fig.39. Methods of quenching of taps at heat treating operations.
1/ correct ; 2/ incorrect ; 3/ reject.

Heat treatment of threading dies

Dies and threading dies are used for the thread cutting of bolts . They are mostly made of carbon tool steel grade Y10 and rarely of alloy tool steel grades X¹, X², 9XC, B1 and X.

For heat treatment , the threading dies are placed into the furnace M¹-2 , which is preliminary filled with some charcoal or cast iron chips for prevention of decarburization of dies . Holding of dies in the heating furnace must be at minimum , in order to secure only the surface hardening of the die threading. The dies made of carbon tool steel are quenched in water with a quick transfer of them into the oil. Dies made of alloy tool steel are quenched in oil.

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In order to secure the toughness of the locking part of the die, it is necessary to wrap it tightly with an asbestos cord; in this case, the wrapped part of the die, while at hardening, would be cooled much slower and would not be subjected to hardening.

The hardness of the dies after hardening should be within the limits $HRC = 58-62$, and the hardness of the locking part not over $HRC = 50$.

After hardening, the threading die is subjected to tempering at once. Dies without tempering may be crushed by the inner residual stresses.

The tempering of hardened dies is carried out at a temperature of $220-240^{\circ}C$ during 1 - 1.5 hours.

The locking / springing/ part of the threading die must be subjected to additional tempering, in order to secure its better toughness. For this treatment, the locking part of the die is heated for a few seconds in a gas burner's torch / until blue colour of tempering appears / and all the die is quenched in water.

Heat Treatment of drills

Drills are made of carbon tool steel grades Y10 Y12 and alloy tool steel grades B1, 9XC, X¹, XB¹.

For heat treatment, the drills are placed into the furnace M// -2 and heated up to a temperature specified for these steels in tables 18 and 20. To prevent decarburization the drills must be heated in the cast iron chips. Quenching of drills, over 12 mm in diameter, is accomplished in water with a transfer into the oil; ~~unal-~~ 2074

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ler size drills / less than 12 mm in diameter / are quenched in oil . Submergence of drills into the quenching liquid must be strictly vertical.

The tempering of drills is carried out in an oil bath at 150-250°C during 1-2 hours / the higher the temperature of tempering , the lesser time of tempering must be applied /. Besides this , an additional local tempering of the tail part of the drill must be done in a gas burner's torch with a quick cooling of the whole drill in water.

The hardness of the working part of the drill after heat treatment should be HRC 61.

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Chapter VIII

HEAT TREATMENT OF ALUMINUM ALLOYS

1. Aluminum

Pure aluminum is a white silvery metal, quite plastic and light. The specific weight of aluminum is 2.7 gr./cm.^3 , the melting temperature is 658°C .

Pure aluminum is marked with a letter A, which is followed immediately by digits indicating the degree of purity of aluminum in percentage / A99.7; A99.5/.

The physical properties of pure aluminum are low: its tensile strength $\sigma_B = 6 \text{ kg/cm}^2$, hardness $H_{\text{B}} = 25 \text{ kg/mm}^2$, relative elongation $\delta = 35\%$. However, the quality of aluminum is greatly improved, when some addition of copper, magnesium, manganese and some other elements is made. Therefore, aluminum alloys and not pure aluminum found its widespread application in machinebuilding. Of particular importance are aluminum alloys, which received wide application in modern aircraft technique owing to their high strength and low specific weight.

Aluminum alloys are used as sheets, tubing, shapes and rivets for repair of aircraft technique at military conditions.

2. Duralumin

Duralumin alloys are widely applied for military repair of aircraft technique, therefore we shall discuss in detail, the properties and methods of heat treatment

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of these alloys.

Properties of Duralumin

The composition of duralumin, besides aluminum, consists of copper / 3.8-5.2 per cent / , magnesium / 0.4 - 1.8 per cent / , manganese / 0.3-1.0 per cent/. Besides these useful alloying elements, duralumin always contains some silicon and iron -- admixtures which get into an alloy from a raw material.

Iron is a harmful impurity. Therefore the quality of aluminum is judged by the content of iron in it.

Manganese is added to aluminum alloy for increasing of its corrosion resistance.

When introduced into aluminum alloy, the copper, magnesium and silicon form chemical compounds, the most simple of which may be expressed by the formulae of CuAl_2 and Mg_2Si . On heating, these compounds dissolve in aluminum and form solid solutions with it. The higher the temperature of the duralumin heating, the greater would be the number of chemical compounds particles transferred into the solid solution and vice versa, the lower this temperature, the lesser would be the number of particles dissolved in the alloy.

In this way, the concentration of soluble chemical compounds / CuAl_2 and Mg_2Si , etc. / in solid solution would increase or decrease depending on the rise or drop of temperature. A definite maximum solubility of these compounds in a solid solution corresponds to each definite temperature.

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The heat treatment of duralumin alloys is based on the ability of chemical compound particles CuAl_2 , Mg_2Si and others, to dissolve in aluminum at its heating, and to change their shape and value depending on the temperature of alloy heating, the time holding and the rate of its cooling.

The maximum solubility of copper in aluminum at temperature of 548°C is 5.65 per cent. With lowering of temperature the solubility of copper decreases. For instance, at temperature of 400°C it is possible to dissolve only 1.5 per cent of copper.

Let us take for example an alloy Al_6 , in which the copper content is from 3.6 to 4.9 per cent, and heat it to the temperature of 500°C . At this temperature 4 per cent of copper would transfer into a solid solution. What takes place in this alloy on cooling.

If the cooling is conducted slowly, then the copper, dissolved in the solid solution, would gradually separate from it in a form of particles of CuAl_2 . The quantity of copper remaining in the solid solution at this process would continuously decrease. At a room temperature the structure of the alloy would consist nearly of pure aluminum and coarse particles of the chemical compound CuAl_2 . These particles have a round shape and almost do not strengthen the alloy like separate isolated stones immersed into a soft asphalt./ goudron/.

Therefore, slowly cooled duralumin possesses great toughness and plasticity, near to the pure aluminum.

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but it has low hardness and strength.

If the alloy is cooled quickly in water, then the particles would not have time to separate from solid solution and as a result of this all the copper would dissolve in the solid solution. This alloy would consist only of grains of solid solution.

This alloy is a soft, plastic material, easily subjected to forging, stamping and other kinds of plastic deformation.

However, it appears that these properties the duralumin retains only for a short period of time / actually for 2-3 hours /. Upon expiration of this time, even at room temperature, some changes take place in the alloy, which lead to the strengthening of the alloy and to increasing of its hardness and ultimate strength. The strengthening of duralumin is connected with rearrangement of copper's atoms inside the space lattice of the solid solution. This rearrangement leads to the concentration of copper atoms at definite zones of crystalline space lattice causing its distortion and ^{at} the same time the strengthening of the alloy.

The phenomenon of strengthening of duralumin is called ageing.

If the ageing takes place at a room temperature, then it is called natural ageing, however if it happens at a raised temperature, let us say at 100-150°C, then it is called artificial ageing.

The ability of duralumin to strengthen gradually after a quick cooling from a temperature of 500°C, is the basis for its heat treatment.

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Heat Treatment of Duralumin

Heat treatment of duralumin includes its strengthening / hardening , ageing / and destrengthening of hardened and aged alloy / annealing/.

The process of duralumin strengthening consists of the following operations:

1. Heating to a temperature , securing the most complete transformation of chemical compounds of CuAl_2 and Mg_2Si and others , into a solid solution.
2. Quick quenching in water .
3. Ageing of alloy -- i.e. holding it at a room temperature for a definite period of time / 5-7 days/.

Hardening

Hardening includes heating of duralumin and quenching it in water .

Before heating for hardening , the structure of duralumin represents uniform crystals of solid solution and separate inclusions of chemical compounds of CuAl_2 and Mg_2Si / Fig.40,a/. In the process of heating of duralumin, these compounds are dissolved in aluminum , and the higher the temperature of duralumin heating, the greater would be the number of compounds transferred into the solid solution , and the greater would be the effect of heat treatment.

At cooling of the alloy in water, the particles of the chemical compounds are not able to separate from the solid solution and the microstructure of duralumin would be more uniform which can be seen on Fig.40,b. The dark

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particles , observed in the etched microsection, represent iron compounds which at heating did not transform into a solid solution , and also some excessive chemical compounds.

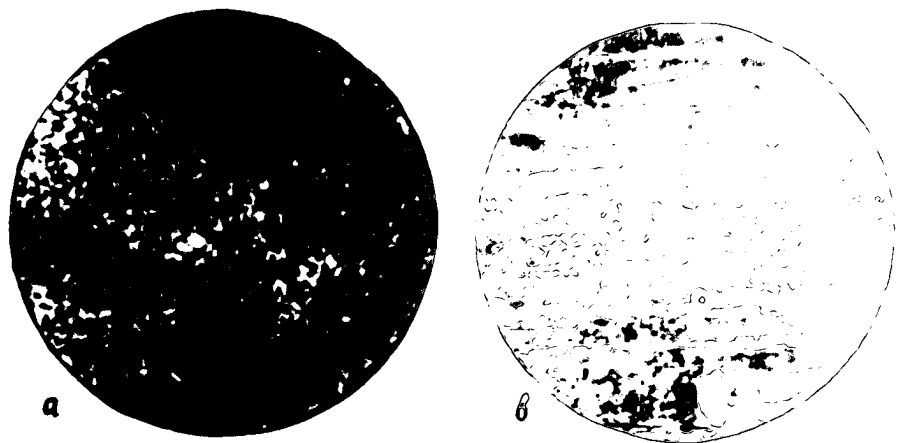


Fig.40. Microstructure of duralumin.
a/ - before hardening / annealed duralumin/;
b/ - after hardening.

For hardening , the duralumin is heated to the temperature of $500\pm 5^{\circ}\text{C}$. It must be borne in mind that physical properties of duralumin , subjected to heat treatment , to a great degree depend on the exact observance of the above-mentioned temperature. Fig.41 shows dependence of physical properties of duralumin on the hardening temperature. As can be seen on the chart , the increase of tensile strength after hardening takes place only up to the temperature of $505-508^{\circ}\text{C}$; after the temperature reaches 510°C , the tensile strength sharply decreases. This takes place, because at the temperature above 510°C , the fusion of the so-called eutectic, disposed on the grain boundaries , takes place . This fact decreases sharply

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the strength of duralumin. In this case it is said that duralumin is overburned. The overburning of duralumin is followed by a sharp drop of relative elongation and ultimate strength. The overburning is easily discovered by a microscopic examination. Fig.42 shows the microstructure of an overburned duralumin. The thin network of the fused eutectic is clearly seen on the grain boundaries.

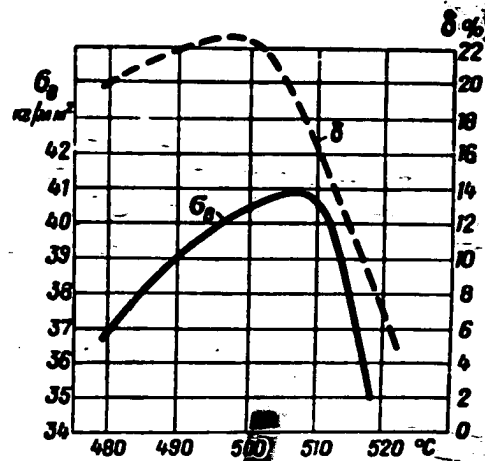


Fig.41 Dependence of physical properties of duralumin on the hardening temperature
a/ temperature of hardening; b/ G_p kg/mm².

The outside indication of overburning is the darkening of the duralumin surface, appearance of blisters and cracks / Fig.43/. In practice, the overburning of duralumin can be easily detected by bending of an article by hands; due to an increased brittleness formed at overburning the article breaks.

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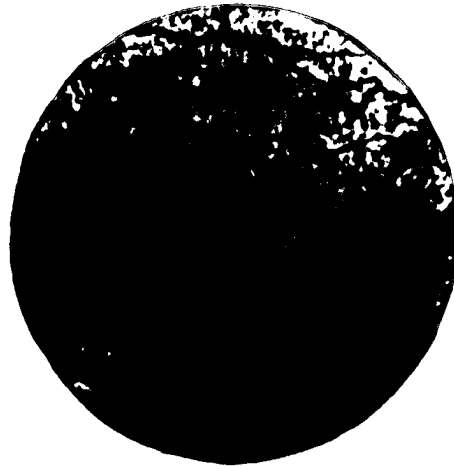


Fig.42. The microstructure of an overburned duralumin.

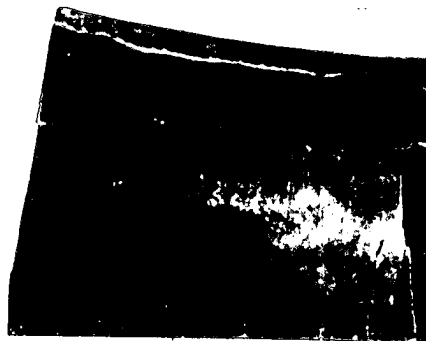


Fig.43. Cracks in an article made of overburned duralumin.

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It is better to heat the articles made of duralumin for hardening in saltpeter bath , inasmuch as the fused saltpeter provides a uniform and fast heating. But in conditions of military repair there are no saltpeter baths available, therefore the following may be used for this purpose : muffle furnace M/1-2 - for heating of small articles , made of duralumin and M/1 type lamp or torch lamp for heating of sheets and shapes. The control of temperature in the furnace M/1-2 is accomplished with a regular thermo-couple with galvanometer. When the M/1 type lamp or torch lamp is used as a source of heating , the thermo-sensitive pencils are used to control the temperature . / Heat treatment of duralumin with utilization of thermo-sensitive pencils is described in chapter IX/.

The holding of duralumin articles in the furnace for hardening depends on the thickness of material /the thicker the material , the longer the holding /, the heating device and the degree of deformation of the material and also on the degree of air circulation in the furnace : the stronger is the air circulation in the heating furnace , the lesser is the holding of articles for heating .

Data on the duration of holding of different thicknesses duralumin articles , at different methods of heating are indicated in Table 21.

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Table 21Holding time for Articles Made of Duralumin of Different Thickness.

Kind of Heating	Thickness in mm										
	0.5	0.6	1.0	1.5	2.0	3.0	4.0	5.0	6	8	10-12
1. Holding in salt-bath, minutes	10	15	15	20	25	30	20	35	40	45	50
2. Holding in furnace, minutes	10	20	20	25	30	35	40	60	90	90	90

When thin aluminum clad sheets of duralumin are hardened, it is not necessary to hold the material in the furnace for a prolonged time, since the copper contained in the duralumin would diffuse / penetrate / into the surface layer of the pure aluminum / clad layer / and lower the corrosion resistance of duralumin.

If multiple hardening of a duralumin sheet is required at a temperature of $500 \pm 5^\circ\text{C}$, the total time of holding of one and the same sheet of 0.5-0.6 mm thick must not exceed 15-20 minutes.

After heating and holding of a duralumin article in the furnace, it must be cooled in water quickly. Usually, water of room temperature / $15-20^\circ\text{C}$ / is used as a cooling medium for hardening of duralumin. To obtain clean and silvery surface of duralumin, sulphuric acid is often added to water / 1 litre of 95% - sulphuric acid to 1m^3 of water /.

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The method of submergence of duralumin articles into a cooling medium for hardening has a great importance. The articles are submerged in water with their thinnest cross section. Fig. 44 shows examples of correct and incorrect submergence of duralumin articles.

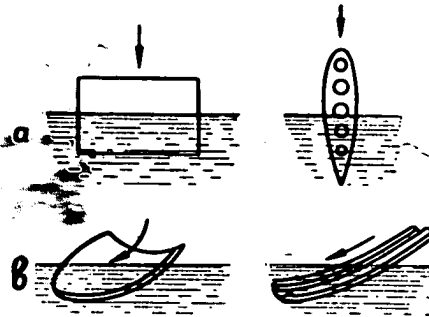


Fig. 44. Submergence of duralumin articles into water for hardening.
a/ - correct ; b - incorrect .

To obtain good results of hardening , it is necessary to try to keep the period of time , between the withdrawal of duralumin articles from the heating furnace to submergence of them into water , at a minimum / not more than 10 seconds / , as otherwise the duralumin may get cold and hardening of the articles would take place from much lower temperature than it is necessary , which would cause the lowering of duralumin quality .

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Ageing of Duralumin

Immediately after hardening, the duralumin during 2-3 hours remains soft, plastic and is easily subjected to different kinds of technological operations.

Due to this fact, it is necessary all technological operations / bending, hammering, etc. / to carry out during the first two-three hours after hardening.

On expiration of this time the ageing of duraluminum takes place.

Fig. 45 shows, how the physical properties of duralumin / the ultimate strength / change depending on the duration of time of ageing.

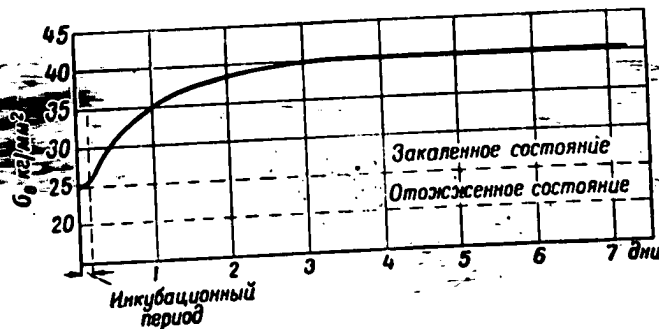


Fig. 45. Curve of natural ageing of duralumin :
1/ Incubative period ; 2/ Annealed state ; 3/ Hardened state; 4/ Tensile strength σ kg/mm².

The process of ageing may be intensified considerably, if it is conducted at increased temperatures / 150-160°C/ In this case, the groups of copper atoms, dissolved at the beginning in the crystalline space lattice of alumi-

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num., separate as finely dispersed particles of CuAl₂ along the grain boundaries and inside of the grains.

The separated particles block the sliding planes in the alloy grains, thus creating difficulty for the alloy deformation. An artificially aged alloy is less plastic than the naturally-aged alloy, and it possesses lesser corrosive resistance. The higher the temperature of artificial ageing, the lower are the physical properties obtained.

Usually, the duralumin is subjected only to natural ageing at a room temperature.

Low-temperature hardening

If hardened and naturally aged duraluminum is subjected to heating at a temperature interval of 200-300°C during a short time, and then quickly cooled, then the duralumin becomes again soft and plastic, i.e., it possesses the property of a freshly hardened alloy. Hardened in such a way duralumin may be subjected to different kinds of technological operations, same as duralumin after usual hardening.

Storing of duralumin at room temperature after low-temperature hardening leads also to the natural ageing. This phenomenon in the alloys of the duralumin type, became known as "the return" of properties.

Low-temperature hardening may be applied only to hardened and naturally aged duralumin. Artificially aged duralumin does not possess the ability to return the properties.

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For low-temperature hardening the duralumin is best heated in a saltpeter bath since the latter provides a uniform and fast heating. The temperature control is effected with thermo-couples.

The time of holding of duralumin, at heating for hardening, depends on the temperature: the higher the temperature of holding, the lesser is the holding for heating.

The optimum temperature of low-temperature hardening for duralumin grades DLAT and DL6AT is the temperature of 275°C and holding 20 ± 5 seconds / in saltpeter bath/.

Suffice it to say that at low-temperature hardening, on removing of cold working takes place. Duralumin articles of intricate shape, which require a secondary hardening for removing of cold working and new destrengthening, must be subjected to regular hardening from the temperature of $500 \pm 5^{\circ}\text{C}$.

If saltpeter baths are not available, then the low-temperature hardening may be conducted through heating the article with an A - type lamp or torch lamp. The heating in this case must be controlled with thermo-sensitive pencils / see Chapter IX /.

Annealing

Annealing of duralumin has the following purpose:
a/ to remove stresses developed at the process preceding the cold working by pressure, and to reinstate the lost plastic properties to the material; b/ strengthening of hardened and aged alloy, extracting

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from it the basic components in a form of free chemical compounds.

The microstructure of duralumin after annealing consists of grains of solid solution, from which copper, silicon and other additions of alloy segregated completely. In such condition the duralumin possesses high plasticity and can be subjected with an ease to mechanical working, stamping, etc.

The optimum temperature of annealing is the temperature of 340°C . At this temperature the particles of chemical compounds CuAl_2 and Mg_2Si are easily separated from the solid solution and they are enlarged. Heating above the temperature of 350°C leads again to dissolving of separated particles of chemical compounds and this is undesirable due to the possibility of partial hardening of the alloy.

In case of heating of duralumin at annealing above the temperature of 350°C , it must be cooled slowly / at the rate of 60°C per hour / in the furnace to the temperature of 300°C and then cooled in the air.

Table 22 shows the method of annealing of hardened and aged duralumin, with the purpose of its strengthening.

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Table 22Methods of Annealing of Duralumin

Characteristic of Material	Technical Specification		Recommended for maximum softening		
	Annealing temperature °C	Time in Minutes	Initial annealing temperature °C	Finishing temperature of annealing °C	Rate of cooling up to finishing temperature degree/hour
Duralumin in hardened condition	340	10	30-60	420-450 240-260	30

Methods of intermediate annealing intended for removing of cold working at the manufacture of articles made of annealed duralumin / D16M/, are shown in Table 23.

Table 23Methods of Annealing of Duralumin for Removing of Cold Working

Annealing temperature °C	Thickness of Material mm	Time of holding at annealing temperature, in minutes		
		Saltpeter bath	In furnace with forced air circulation	In furnace with still air
335-350	0.3-1.8	30	40	60
	2.0-4.0	40	50	80
	4.5-6.0	50	60	90

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Marking of Duralumin and Heat Treatment of Some
Alloys of this Type

Alloys of duralumin type are designated as follows:
D1AT, D1CAT, D1CA⁵TH, etc.

Letter D denotes duralumin, digit following this letter is conditional designation of the alloy; letters following digits denote the state of alloy: A - improved alloy; T - hardened and naturally aged; M - annealed / soft /; ⁵ - non-clad; H - cold worked.

Decoding of some grades of duralumin is given below:

D1CA⁵M - non-clad, annealed;

D1CA⁵T - non-clad, hardened and naturally aged;

D1CA⁵TB - non-clad, hardened and naturally aged with improved quality of rolling;

D1C⁵TH - non-clad, cold worked after hardening and natural ageing;

D1CA⁵THB - non-clad, cold worked after hardening and natural ageing with improved quality of rolling;

D1CA⁵THBC and D1CATHBC - cold worked after hardening and natural ageing with high quality of rolling.

If in the alloy designation, there is no letter ⁵ / for instance D1CM, D1CT, etc. /, it means that the duralumin sheets are aluminum clad. What is aluminum plating of duralumin?

It is known that the duralumin is to a greater degree subjected to corrosion, than the pure aluminum. Therefore, to increase the corrosion resistance, during rolling the duralumin is clad with a thin layer of pure
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aluminum. The thickness of the clad layer is 6 - 10 per cent of sheet thickness, i.e., 3-5 per cent on each side. The chart of duralumin plating is shown in Fig. 46.

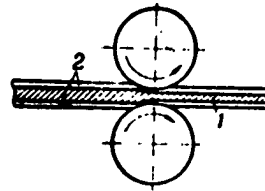


Fig. 46. Chart of duralumin plating :
1/ duralumin subjected to plating ; 2/ pure aluminum.

At present time, duralumin clad with aluminum is manufactured mainly as sheets. Fig. 47 shows the microstructure of duralumin clad with pure aluminum.

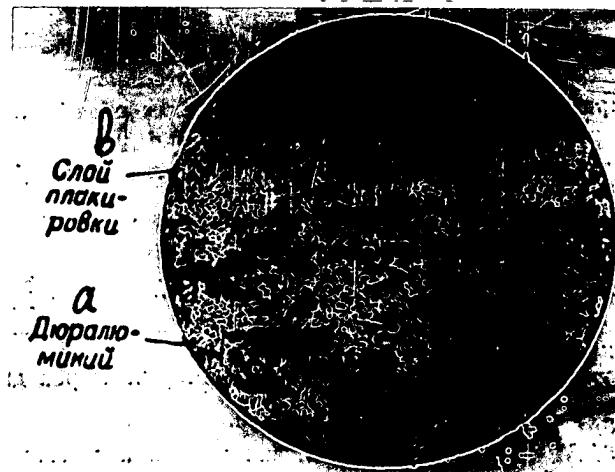


Fig. 47. Microstructure of duralumin clad with pure aluminum.
a/ duralumin ; b/ layer of clad aluminum.

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The chemical composition of basic grades of duralumin is shown in Table 24.

Table 24.

Chemical Composition of Basic Grades of Duralumin					
Grade of Duralumin	Content of Chemical Elements, per cent				
	Copper	Magnesium	Manganese	Silicon	Iron
				Maximum	
D1	3.8-4.8	0.4-0.8	0.4-0.8	1.0	1.0
D6	4.6-5.2	0.65-1.0	0.5-1.0	0.5	0.5
D16	3.8-4.9	1.2-1.8	0.8-0.9	0.8	0.8

Physical properties of alloys of duralumin type are shown in Table 25.

Table 25

Physical Properties of Alloys of Duralumin Type		
Grade of duralumin	Tensile strength	Elongation,
	kg/mm ² minim.	per cent
D16AM	23	12
D16AT	42	13
D16A ⁵ F	45	12-14
D16A ⁵ M	24	11-12
D16A ⁵ TH	48.5	9-11
D1AM	23	12
D1AT	38	15
D95AT	49	7
D6M	22	15
D6T	46	15

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Methods of heat treatment of some basic grades of duralumin , and their application are given below.

Duralumin grade D1 is used for power elements of airplane structure of medium strength / parts of airframe, stamped units of fastening , struts , blades of air screws , etc ./

This alloy is subjected to the following heat treating process : hardening in water from a temperature of 490-510°C , natural ageing during 4 days . Annealing of the alloy is conducted at a temperature of 350-370°C with air cooling.

Duralumin grade D16 of higher strength is used for power elements of airplane structure / parts of airframe , sheathing , frames , ribs , longerons , rivets, etc. /. The plasticity of this alloy in freshly-hardened condition is not high / medium/. Duralumin of grade D16 is subjected to the following heat treatment : hardening in water from a temperature of 495-505°C, natural ageing during 4 days . Annealing of this alloy is conducted at a temperature of 350-370°C with air cooling.

Rivets made of duralumin grade D16 are placed into an airplane structure in a freshly-hardened condition, but not later than 20 minutes after hardening.

At present time , high strength aluminum alloy B 95 is used for the manufacture of airplane parts, subjected to heavy loading. The basic elements in this alloy are magnesium and zinc.

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This alloy is used for the manufacture of power elements of air frame structure / longerons, stringers, frames, sheathing, ribs, etc./. The hardening of the alloy is accomplished from a temperature of 465-480°C with cooling in water. An artificial ageing is necessary after hardening of aluminum clad parts at a temperature of 120°C for a period of 24 hours, of non-clad alloy -- at a temperature of 140°C for 16 hours. Annealing of alloy is done at a temperature of 420°C with cooling in the furnace to the temperature of 150°C and further in the air.

3. Cast Aluminum Alloys

Cast aluminum alloys are marked with letters "A" and a digit, which indicates the alloy number / for instance A-1, A-7, etc./.

Chemical composition and physical properties of some of the most useable cast aluminum alloys are given in table 26.

Methods of heat treatment of the most widely used cast aluminum alloys, and articles manufactured from these alloys, are given below.

Alloy A-1- aluminum-copper alloy with nickel. It is utilized for casting of pistons, aircraft engine cylinder heads and other parts, operating at high temperatures. The casting properties of this alloy are low, the alloy is apt to develop cracks, tripping, friability and gas porosity.

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Table 26

Chemical Composition and Physical Properties of Cast

Aluminum Alloys								
Grade or Alloy	Content of Chemical Elements, per cent							
	Silicon	Manganese	Iron	Copper	Zinc	Nickel	Magnesium	
1	2	3	4	5	6	7	8	
Al 1	-	-	0.6	8.75-4.5	0.8	1.75-2.25	1.25-1.75	
Al 2	10-18	-	0.8	-	0.8	-	-	
Al 3	4-6	0.2-0.8	1.0	1.5-3.5	0.5	-	0.2-0.8	
Al 4	8-10.5	0.25-0.5	0.6	-	0.8	-	0.17-0.3	
Al 5	4.5-5.5	-	0.7	1.0-1.5	0.3	-	0.35-0.6	
Al 6	4.5-6.0	-	1.8	2-3	0.3	-	-	
Al 7	-	-	1.0	4-5	0.03	-	-	
Al 8	-	-	0.8	-	0.1	-	9.5-11.5	
Al 9	6.5-7.5	-	0.6	-	0.8	-	0.2-0.4	
Al 12	-	-	1.8	9-11	1.0	-	-	
Al 18	0.8-1.3	0.1-0.4	0.5	-	0.2	-	4.5-5.5	

Tensile strength $\frac{S}{B}$ kg/mm ²		Elongation, % per cent	Hardness HB kg/mm ²
9	10	11	
20	0.5	25	
18	8	35	
20	9	75	
28	8	70	
20	-	70	
16	1.0	45	
25	5	80	
30	12	70	
20	6	55	
17	1.0	100	
20	5	70	

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The method of heat treatment of this alloy is as follows: heating at a temperature of $515 \pm 5^\circ\text{C}$ during 2-4 hours, quenching in boiling water, ageing at a temperature of $225 \pm 5^\circ\text{C}$ during 2-4 hours, cooling after ageing in the air.

Alloy grade A.12 - aluminum-silicon alloy. It is used for castings of intricate shaped articles, which are not subjected to considerable loads. This alloy possesses excellent casting and technological properties and has high fluidity. There are no strengthening additions in the alloy A.12, therefore heat treatment of this alloy is ineffective.

Alloy grade A.13 - aluminum-silico-copper alloy with magnesium and manganese. It is utilized for casting of aircraft instruments bodies, and accessories, and also for casting of aircraft engine small parts. The alloy A.13 is subjected to the following heat treatment: heating to the temperature of $525 \pm 5^\circ\text{C}$, holding at this temperature for 5-6 hours and consequent ageing at 180°C during 5 hours.

Alloys grades A.14 and A.15 are used for casting of large parts of aircraft engines: bodies, blocks, housings, etc. The casting properties of alloy A.14 are very good, and of the alloy A.15 somewhat lower.

Methods of heat treatment of the alloy A.14 are as follows: heating up to a temperature of $525 \pm 5^\circ\text{C}$, holding at this temperature for 2-6 hours, quenching in hot water / $50-100^\circ\text{C}$ / , ageing at a temperature of $175 \pm 5^\circ\text{C}$ during 15 hours, cooling after ageing in the air.

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Methods of heat treatment of the alloy A. 5 are as follows: heating up to a temperature of $525 \pm 5^\circ\text{C}$, holding at this temperature not less than 4 hours, quenching in boiling water, ageing at a temperature of $180 \pm 5^\circ\text{C}$ during 5 hours.

Alloy grade A. 6 - aluminum-silicon alloy with copper. It is used for casting of carburettor's parts and accessories. The casting properties of this alloy are good. The alloy A. 6 is subjected to ageing at a temperature of $290 \pm 10^\circ\text{C}$ during 3-5 hours.

Alloy grade A. 7 - aluminum-copper alloy. It is utilized for airplane parts of medium loading and relatively simple configuration: control and instrument brackets, swing pedals, fuselage and empennage. Methods of heat treatment of this alloy are as follows: heating to a temperature of $515 \pm 5^\circ\text{C}$, holding at this temperature for 10-15 hours, quenching in water of room temperature with consequent ageing at a temperature of $180 \pm 5^\circ\text{C}$ during 2-4 hours.

Alloy A. 8 - aluminum-magnesium alloy. It is used for main units and parts of simple configuration, which are subjected to impact loads and action of corrosion.

The following method of heat treatment is used for this alloy: heating up to a temperature of $485 \pm 5^\circ\text{C}$, holding at this temperature for 15-20 hours, quenching in water or oil at a temperature of $50-100^\circ\text{C}$.

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Heating or hardened aircraft parts above the temperature of $100-125^{\circ}\text{C}$ is not permitted, inasmuch as in this case quick disintegration of solid solution takes place and physical properties of parts are considerably lowered. It is prohibited categorically to subject to heat treatment articles made of this alloy in a saltpeter bath, since the aluminum-magnesium alloys possess a great affinity for oxygen, in which the saltpeter is quite rich.

Alloy A. 9- aluminum-silicon alloy with magnesium. It is used for the manufacture of aircraft parts of medium strain and intricate configuration. This alloy can be easily welded by gas welding. The following method of heat treatment is used for this alloy: heating up to a temperature of $535\pm 5^{\circ}\text{C}$, holding at this temperature not less than 12 hours, quenching in water.

Alloy grade A. 12- aluminum-copper alloy. The high copper content imparts to this alloy great hardness and increased heat resistance, but also increases alloy's brittleness. It is used for small lightly loaded aircraft parts.

Method of heat treatment of the alloy A. 12 is as follows: heating up to a temperature of $535\pm 5^{\circ}\text{C}$, holding at this temperature for 2-6 hours, quenching in water, ageing at a temperature of $175\pm 5^{\circ}\text{C}$, for which the alloy is held for 15 hours, with a following cooling in the air.

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Alloy grade A 13- aluminum-magnesium alloy with silicon and manganese. It is utilized for the manufacture of aircraft parts of medium strain, working in conditions of corrosions attacks. This alloy is not subjected to heat treatment.

4. Strained Aluminum Alloys

Alloys of AM¹ and AM² -type

Alloy AM¹ - is aluminum-magnesium alloy and AM² - aluminum-manganese alloy.

Manganese, introduced into aluminum, increases its corrosion resistance and strength. Magnesium introduced into aluminum in a quantity of 2-3 per cent, decreases the specific weight of aluminum, increases its strength without lowering of its plasticity, which to a considerable degree contributed to the widespread application of this alloy.

Alloys type AM¹ and AM² are used in cold worked and annealed condition, they are not subjected to hardening. Cold working represents the only method of strengthening of these alloys.

The chemical composition and physical properties of alloys of the above mentioned, type are given in Tables 27 and 28.

Table 27

<u>Chemical Composition of Alloys AM¹, AM², AM³ 5</u>				
<u>Grade of Alloy</u>	<u>Content of Chemical Elements, per cent</u>			
	<u>Magnesium</u>	<u>Silicon</u>	<u>Copper</u>	<u>Manganese</u>
	<u>m a x i m u m</u>			
AM ¹	0.05	0.6	0.2	1.0-1.6
AM ²	2.0-2.8	0.4	0.1	0.15-0.4
AM ³ 5	4.7-5.7	0.4	0.2	0.2-0.6

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The strength of the alloy in the annealed condition -
 Table 26

Physical Properties of Alloys AM ₁ , AM ₂ , AM ₃		Physical Properties		
Grade of Alloy	Condition of Material	Tensile Strength kg/mm ²	Elongation per cent	Hardness kg/mm ²
AM ₁ & AM ₂	Annealed	13	20	30
AM ₃	Half hard	16	10	40
AM ₄ & AM ₅	Hard	22	5	55
AM ₆ & AM ₇	Annealed	20	23	43
	Half hard	25	6	60
AM ₈ & AM ₉	5M Annealed	27	23	65

Alloy AM₁ is used for the manufacture of welded fuel tanks, for gasoline and oil lines and for other lightly loaded aircraft parts made by deep drawing. The alloy possesses good resistance to corrosion, near to the corrosion resistance of pure aluminum. It has high plasticity in annealed condition / alloy grade AM₁ & AM₂, medium plasticity in half hard condition / alloy grade AM₃, low plasticity in hard condition / alloy grade AM₄ & AM₅. The alloy is welded well by gas, atomic-hydrogen and resistance welding; the alloy is not strengthened by heat treatment. To eliminate cold working effect, the alloy is subjected to annealing at a temperature of 350-410°C with cooling in the air.

The alloy grade AM₆ is used same as alloy AM₇, for welded fuel tanks, gasoline and oil lines, and for medium loaded aircraft parts.

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The strength of this alloy in the annealed condition is almost the same, as the strength of alloy grade AM in hard condition.

To remove the effect of cold working, the alloy is subjected to annealing at a temperature of 350-410°C. This alloy possesses good resistance to corrosion.

Aluminum Alloys for Rivets

The chemical composition and physical properties of alloys used for rivets making are given in Table 29.

Table 29

Chemical Composition and physical properties of alloys used for the manufacture of rivets.

Grade of Alloy	Chemical Composition, per cent						Shearing strength kg/mm ²	Hardness kg/mm ²
	Copper	Magnesium	Manganese	Iron	Silicon			
D18	2.2-3.0	0.2-0.5	0.2	≤0.5	≤0.5		21	70
D3	2.6-3.5	0.3-0.7	0.3-0.7	0.5	0.5		24	80
B65	-	-	-	-	-		25	-

Alloy grade D18. This alloy possesses high plasticity and is used as one of the basic riveting materials. Rivets made of this alloy may be placed in an aircraft structure in hardened and naturally aged condition; plasticity of rivets in this condition is quite satisfactory and that is preferable as against rivets made of alloys which require restrengthening before placing them into the airplane structure.

Hardening of the alloy grade D18 is conducted from a temperature of 490-505°C with quenching in water, the natural aging takes place for 4 days.

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Alloy grade D3 $\frac{1}{2}$. Rivets made of this alloy are placed into airplane structure in freshly hardened condition , not later than 3 hours after hardening took place. After expiration of 3 hours after hardening , the alloy must be restrengthened by way of annealing. The annealing is accomplished at a temperature of 340-370°C with cooling in the air. The plasticity of this alloy in the annealed condition is high. The hardening of the alloy is made from a temperature of 490-500°C with cooling in water. The natural ageing continues for 4 days.

Alloy grade B65 . Rivets made of this alloy are placed into airplane structure in an aged condition, inasmuch as the alloy has a satisfactory plasticity and the rivets do not have to be restrengthened before setting them into airplane structure.

Hardening of the alloy grade B65 is performed from a temperature of 510-520°C with quenching in water. Ageing takes place at a room temperature during 10 full days, and at a temperature of 50°C - during 3 days.

Alloys type AK

Aluminum alloys type AK / letter "K" denotes "forged" / are used for forged and stamped aircraft parts / for instance , airscrew blades , impellers , etc. / Besides high physical properties, these alloys possess good plasticity in hot condition. Some of these alloys / grades AK2, AK4 / are heat resistant , i.e. possess high physical properties at elevated temperatures / 200-300°C /. Heat resistant alloys are applied for the manufacture of parts, operating in conditions of high temperatures / pistons, blades of

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guiding apparatus , etc./

Physical properties and chemical composition of some strained aluminum alloys of AK type , in the condition of their highest strength , are given in Table 30 / after hardening and ageing/.

Table 30

Chemical Composition and Physical Properties of

Strained Aluminum Alloys AK Type						Tensile strength kg/mm ²	Elongation per cent	Hardness HB kg/mm ²
Grade of Alloy	Chemical composition, per cent							
	Copper	Magnesium	Manganese	Nickel	Silicon			
Minimum								
AK2	3.5-4.5 0.4-0.8	up to 1.8-2.8 0.2	up to 0.8 0.5-1.0			24	4	95
AK4	1.9-2.5 1.4-1.8	up to 1.0-1.5 0.2	0.5-1.5 1.1-1.6			38	4	100
AK6	1.8-2.6 0.4-0.8	0.4-0.8	up to 0.8 0.8			38	6	95
AK8	3.9-4.8 0.3-0.7	0.4-1.0	up to 1.0 1.0			46	10	130

Methods of heat treatment for these alloys are given below.

Alloy grade AK2 / heat resistant alloy/ is used for the manufacture of aircraft engine pistons and other parts , working at high temperatures . It is easily welded by spot and roller welding.

Heat treatment of this alloy is as follows: hardening from a temperature of 515±5°C with quenching in water,

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artificial ageing at a temperature of 170°C during 12-15 hours.

Alloy grade AK4- a most widespread heat resistant alloy, used for the manufacture of aircraft engine pistons, compressor's parts of jet-propulsion aircraft engines and other parts working at high temperatures. It is subjected to the following heat treatment: hardening from a temperature of $515\pm 5^{\circ}\text{C}$, artificial ageing at a temperature of 170°C during 16 hours.

Alloy grade AK6 is used for the manufacture of forged and stamped aircraft parts / of intricate shape /, of medium strength. It is utilized alongside with the alloy grade D1, where high plasticity in hot condition, is required. The forging / stamping / temperature for this alloy is $470-475^{\circ}\text{C}$. Hardening of this alloy is performed from a temperature of $500-515^{\circ}\text{C}$ with quenching in water. After hardening, the article is subjected to artificial ageing at $150-160^{\circ}\text{C}$ during 12-15 hours.

Alloy grade AK8 has an increased strength; the plasticity of this alloy in hot condition is not as good as of the alloy grade AK6. At present time it is substituted by the alloy grade B95.

The forging / stamping / temperature of this alloy is $450-475^{\circ}\text{C}$. Hardening of the alloy is performed from a temperature of $500-510^{\circ}\text{C}$ with quenching in water. After hardening the alloy is subjected to artificial ageing at $150-160^{\circ}\text{C}$ during 12-15 hours.

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Chapter IX

HEAT TREATMENT OF DURALUMIN WITH UTILIZATION OF THERMO-SENSITIVE PENCILS

1. The Essence of the Method

In order to manufacture any aircraft part made of duralumin, it is necessary preliminary to restrengthen it. For temporary restrengthening of duralumin, it is recommended to harden it, utilizing the thermo-sensitive pencils.

The essence of the heat treatment of duralumin, utilizing the thermo-sensitive pencils, is as follows: the surface of the duralumin blank intended for restrengthening / hardening / is marked with hachures of a thermo-sensitive pencil and then heated by A-22-type lamp or a torch lamp. The heating temperature of duralumin for hardening, is judged by a change of colour of hachurs, marked by a thermo-sensitive pencil on the surface of the heated blank. The pencil's hachurs, at a definite temperature, for which the pencils have been designed, change their colour sharply. This will prove that the necessary temperature is reached. At a sharp change of hachur's colour, the heated blank is quickly submerged into water. Restrengthened, as a result of this operation, duralumin may be subjected to different kinds of deformation, after 2-3 hours of hardening.

To conduct such heat treating operations of duralumin, it is necessary to possess minimum 2 thermc-sensitive pencils :

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a/ one - which changes its colour at a temperature of 490°C / for regular hardening of duralumin grades D1T , D1AT, D16T . D16AT . etc./.

b/ Another pencil , which changes its colour at a temperature of 270°C / for lowtemperature hardening of duralumin grades D16T, D1T, D16AT and D1AT/.

Besides these pencils , it is desirable to use some pencils which can fix the upper and lower limits of heating temperature at heat treatment of duralumin. For example, for regular hardening of duralumin of all grades , besides the pencil designed for temperature of 490°C , it is necessary to have pencils designed for temperatures of 480 and 500°C ; for low-temperature hardening of duralumin grades D16AT , D1AT , the pencils have been designed for temperatures of 260 and 280°C . Pencils , designed for temperatures of 480° and 500°C are necessary for the purpose that the worker who conducts hardening of duralumin, may heat the aircraft part without apprehension of its over heating.

The pencil's hachurs , which change their colour at a temperature of 480°C , warn the operator that the temperature of the heated article is near to the hardening temperature of 490°C . The change of colour of the pencil's hachure, designed for temperature of 500°C , would indicate to the operator that it is necessary to stop heating the article immediately , in order to avoid overburning of duralumin.

The thermo-sensitive pencils represent wax rods pigmented with thermo-sensitive chemical compounds .

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The pencil's wrapper is marked with the temperature of the colour change / for example 480°C / and the colour which the hachures, marked on duralumin sheet with the pencil, would take when the temperature of the colour change has been reached.

2. The Process of Hardening

Heating for hardening of duralumin blanks and aircraft parts, of large dimensions but not over 0.6×1.2 metres, is recommended to carry out with a $\text{A} \cdot \text{L} \cdot \text{L}$ -lamp; when small size duralumin blanks and also narrow articles /shapes, tubes, etc / are subjected to heating, it is better to use a torch flame for this purpose. Hardening with utilization of thermo-sensitive pencils may be applied only for hardened and aged duralumin from 0.5 to 5.0 mm thick.

Hardening of duralumin, utilizing thermo-sensitive pencils, is conducted as follows. Blank of a duralumin sheet, cleaned of oil and grease, for better marking with pencil's hachures, is preliminary heated to a temperature of $50-60^{\circ}\text{C}$ / control with hand touching/ and hachures of thermo-sensitive pencils, with colour change temperatures of $480, 490$ and 500°C , are marked on its surface. The hachures must be placed in such a way as to make it possible to check the temperature along the whole surface of the duralumin blank.

After marking the duralumin blank with hachures, it is heated by a torch lamp or $\text{A} \cdot \text{L} \cdot \text{L}$ - lamp until the colour of the marked hachures changes. As to the uniformity of heating along the whole surface of the blank, it is judged

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by a simultaneous change of the marked hachures colour. At first, the change of hachures colour, marked with a pencil designed for 480°C , would take place. It would be a warning that the temperature of heating of the part in question, is near to the optimum.

At change of hachures colour, marked with a pencil designed for a temperature of 490°C , the duralumin blank is quickly submerged into water having the temperature of $15-25^{\circ}\text{C}$. The heated blank is hardened by submergence into the water with its thinnest cross-section / rib/, strictly perpendicularly to the water surface.

The time of heating of the duralumin blank to the temperature of 490°C depends on the thickness and dimensions of the blank and the source of heating.

Hardening of duralumin shapes and tubes is carried out in the same way, as the hardening of duralumin sheets. At this, it is necessary to bear in mind that the heating of tubes and shapes for hardening to a greater degree is a local heating, as a result of which the transitional zones from the heated part to the unheated one, may be formed with lowered strength.

Hardening of duralumin blank of greater length /the length of the blank is 3 to 4 times larger than the diameter of the torch / may be performed by two steps: firstly one half of the blank is heated and then the other one.

At this method of hardening it is necessary to take care that the halves of the blank, subjected to hardening, overlap each other, i.e. the hardening is not limited by

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the half of the blank, but spreads somewhat further.

With application of thermo-sensitive pencils, it is possible to conduct hardening of duralumin rivets with the purpose of their restrengthening for riveting. Rivets made of duralumin grades D1T, D1T and D16T may be subjected to hardening. For this purpose, an iron sheet of 800x400 mm and 1-2 mm thick is taken, in which holes of the diameter somewhat larger, than the diameter of the rivets, are drilled. The rivets are set into these holes / Fig.48/. The heads of the rivets, placed into the sheet holes, are marked with hachures of the thermo-sensitive pencils / one or two rivets per each ten rivets /. The sheet with rivets is heated up to the change of colour of hachures and then quickly submerged into water. The flattening of rivets, subjected to heat treatment, is made of :

alloy grade D1T during 2 hours after hardening;
alloy grade D16T during 20 minutes after hardening.
1 rivets

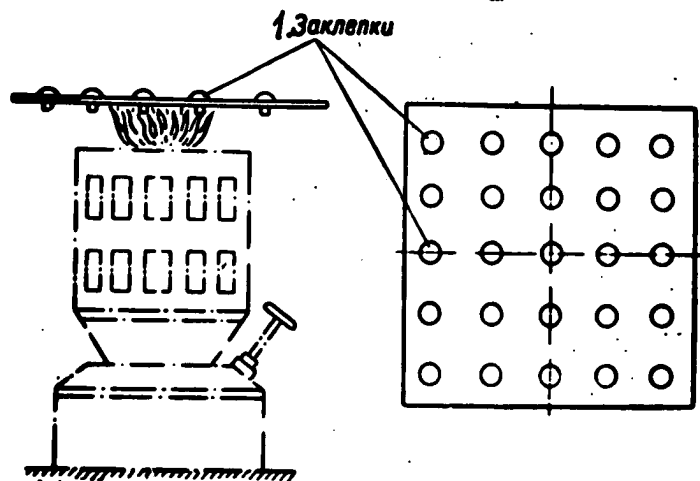


Fig.48. Device for hardening of duralumin rivets.

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If during the specified time the rivets were not used , then it is necessary to harden them anew. Rivets, set into an airplane structure , in the process of natural ageing during 2-3 full days , regain the former physical properties , i.e. are strengthened again.

When heat treatment is conducted in a winter time / with the temperature below zero /, no natural ageing practically takes place, therefore , the finished aircraft^{part} /, before assembly , should be held at a room temperature at least for one full day , for obtaining of the necessary strength.

3. Defects at the hardening of duralumin

Kinds of defects at hardening of duralumin, when it is heated both in the furnaces or with an ~~light~~-lamp or a torch lamp , are practically the same.

One of the most widespread kind of defects at hardening of duralumin is overburning. Usually , after a correctly performed hardening , the duralumin has a bright surface. When the overburning takes place, the surface of duralumin becomes dull , and if overburning is quite intense , blisters may appear on the duralumin surface. At bending , the overburnt duralumin develops cracks and is not suitable for the manufacture of aircraft parts. It cannot be restored ; the overburnt duralumin blank is rejected.

Another kind of defect is an insufficient destrengthening of duralumin after hardening / the material remains hard / due to nonobservance of the heat treating process ; the temperature of heating was lower or the time of holding

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insufficient. Such defect ~~can be remedied~~. For this, it is necessary to repeat the hardening operation to receive the required restrengthening.

4. Low-temperature hardening with utilization of thermo-sensitive pencils.

Low-temperature hardening may be applied, as a regular hardening, for the manufacture of aircraft parts from duralumin sheets. Since this hardening does not eliminate the cold working, it may be recommended for duralumin used for the manufacture of aircraft parts of simple configuration, with a low degree of deformation, when there is no need for multiple restrengthening. When conducting the low-temperature hardening, it is important to bear in mind, that only naturally aged duralumin can be subjected to restrengthening. Artificially aged duralumin cannot be restrengthened.

The low-temperature hardening is similar to regular hardening. The difference is in that, that at regular hardening the thermo-sensitive pencils designed for a temperature of colour change at 480, 490 and 500°C are used, while at low-temperature hardening, the pencils with a temperature of colour change at 260, 270 and 280°C are utilized. The optimum temperature for low-temperature hardening, as it has been mentioned before, for duralumin grades D16T, D1T, D16AT and D1AT, equals to 270°C. Torch lamp or 100W-lamp are used for heating of duralumin for this operation.

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At military repairs of airplanes, the low-temperature hardening may be applied for dressing of crumpled cowls and streamlined parts of airplane.

Inasmuch as hardening for dressing of crumpled cowls or streamlined parts would be of local character, the transitional zones with somewhat lowered strength / by 10-15 percent/ and corrosion resistance are formed between the hardened part and the basic material, which are not essential for cowls and streamlined parts of an airplane.

The order of operations for dressing of crumpled parts of an airplane, with the aid of low-temperature hardening is as follows:

a/ Dirt, grease and oil are removed from the sheet, which is subjected to hardening.

b/ The surface, near the crumpled places, which is not affected by a torch heating flame / for instance, the inside surface of the cowl / is marked with hachures of the thermo-sensitive pencils.

c/ The crumpled part is heated with a torch lamp to the temperature of the colour change of pencil's hachures and then the heated part is quickly quenched with water from a bucket or a hose.

Dressing of the crumpled parts should be carried out during the period of not more than two hours after hardening.

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Chapter X

Temperature Measurement

The quality of heat treatment depends chiefly upon the accuracy with which the required temperature was established and maintained. The control of temperature is accomplished with the aid of measuring instruments.

In this chapter, construction and principles of operation of instruments, used for measuring of temperature of metals and alloys heated for their heat treatment, are considered.

At present time, there are many different measuring instruments which can be used for measurement of temperature of heated articles.

The most simple device used for measurement of temperature is called thermometer. With the aid of thermometer it is possible to measure the temperature but not above 500°C . The temperature above 500°C is taken with pyrometers.

Construction of thermometers and pyrometers is based on the change of properties of the body depending on the temperature. For example, if temperature goes up, many bodies change their volume, electrical resistance and colour. At heating of two interconnected bodies, an electric current-thermoelectricity may develop in them.

Observing the change of any one property, we may judge about the change of temperature.

The property of the body used in the instrument for measurement of temperature must, each time in the same way, change with temperature, be independent of the in-

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fluence of outside factors, be reproducible and finally, to allow accurate measurement by a simple and convenient method.

Depending on the factor which one of the physical properties is used in construction of an instrument for temperature measurement, the pyrometers may be:

1. Dilatometric (based on the change of the body's volume)

2. Electrical resistant

3. Radiant and photometric (optical)

Centigrade scale is approved for temperature measurement. On this scale, the temperature of ice melting (freezing of distilled water) is accepted as 0° ; the temperature of the mercury column) is accepted as 100° . The degrees of this scale are denoted by a sign " $^{\circ}\text{C}$ ".

The thermoelectric pyrometers which found the most widespread application for measurement of metal temperature, will be described here in detail.

1. Thermoelectric Pyrometers

If two conductors of different metals are taken and their ends are soldered, and then the place of junction is subjected to heating, then at the conductors free ends (as it is commonly said, at the couple's ends whence the name of thermocouple was derived) a difference of potentials would appear as a result of which

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the thermal electromotive force / t.e.m.f./ would be generated. This can be easily proved , by connecting the free-ends of conductors at which the electric current would start to flow through the closed circuit / See Fig.49/.

On the contrary , if the electric current passes through such circuit , then besides heating of the conductors with the electric current , the place of their junction is also heated . It is very interesting to note, that if at any direction of the current some rise of junction temperature is observed , then at the opposite direction of the current the temperature lowers.

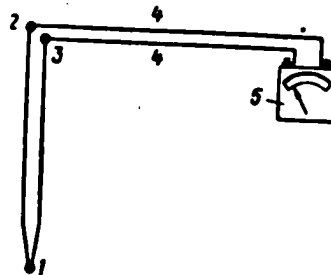


Fig.49. Chart of operation of thermocouple:

- 1. Junction of two conductors ; 2 and 3 - cold ends of thermocouple electrodes; 4 - Copper conductors; 5 - galvanometer.

The difference of potentials , rising at the conductors (ads at heating of the place of their junction , depends on the temperature of the junction heating. With an increase of temperature , the difference of potentials also increases and consequently the value of the thermal electromotive force / temf/ will rise.

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The value t.e.m.f. , besides of temperature , depends also on the material from which the conductors are made, but does not depend on the temperature spreading along the conductor's length.

This phenomenon , i.e. the rise of potentials difference at free conductor's ends at heating of the place of junction , is utilized for measurement of temperature.

Thus , the thermocouple consists of two conductors , two ends of which are soldered and the others are left free. These ends are connected to millvoltmeter / galvanometer / which measures the thermal electromotive force at the ends of the thermocouple. Thermocouple and galvanometer make a pyrometer.

The thermal electromotive force depends on the temperature of the hot junction and the temperature of free ends / cold junction /. Maintaining the temperature of cold junction constant / usually 20°C / , it is possible to graduate the thermocouple , i.e. , to determine the dependence of t.e.m.f. only from the temperature of the hot junction , which affords the possibility to measure the temperature of the bodies according to the value of t.e.m.f. taken by galvanometer . This condition lies at the basis of the thermocouple construction.

The free ends of the thermocouple may be connected to galvanometer through intermediate conductors , if their junctions at temperature measurement show one and the same temperature. The general view of galvanometer with thermocouple / pyrometer / is shown on Fig.50.

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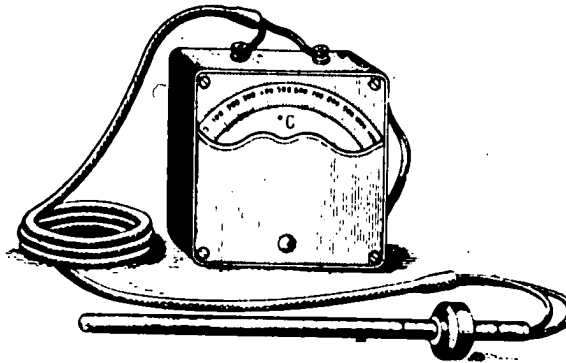


Fig.50. General view of galvanometer with a thermocouple.

It is unnecessary for the heated ends of the thermocouple / hot junction / to touch each other. An intermediate conductor between them may be the tested solid or liquid metal , which is a current conductor .

Materials for Thermocouples

Metals and alloys , used for the manufacture of thermocouples , must meet rather high requirements. They must comply with the following conditions :

to be heat resistant , i.e. , should withstand high temperatures without a change of their chemical and physical properties at these temperatures ;

to possess constant thermoelectrical properties /these properties must not change with time /,

to produce high thermal electromotive force / that increases the accuracy of temperature reading /;

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to have high electric conductivity ;

to have an extensive time of service.

The most widespread thermocouples are made of the following metals :

Platinum vs platinum-rhodium.

Copper vs constantan.

Iron vs constantan

Chromel vs alumel

Nickel vs nichrome

Brief Characteristic of the Most Used

Thermocouples

Platinum vs platinum plus 10% rhodium thermocouple is the most widespread in the practice of measurement of medium / 500-800°C/ and high temperatures / above 800°C/.

This thermocouple may be used for measurement of temperature up to 1600°C , if it is preliminary protected against the action of carbon monoxide /CO/ and also against vapours of metals and silicon vapours .

When this thermocouple is used for measurement of temperatures up to 1200°C , it may serve for a long time without a loss of its high thermoelectric properties.

Platinum vs platinum-rhodium thermocouples of industrial type are usually manufactured with compensating wires / at this , the platinum electrode is jointed with a copper-nickel wire and the platinum-rhodium with a copper wire /.

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The compensating wires permit to remove the cold junction of the thermocouple, from the source of heating and that makes it possible to maintain its temperature constant.

If hot junction of this thermocouple breaks, it can be restored by welding in the flame of a voltaic arc.

Copper vs constantan thermocouple is applied for measurement of low temperatures up to 400°C . Above this temperature, the copper starts to oxidize, that restricts the application of this thermocouple above those temperatures. The copper vs constantan thermocouple develops high t.e.m.f. and is successfully used for measurement of a negative temperature / below 0°C .

Iron vs constantan thermocouple is utilized for temperature measurement up to 570°C , inasmuch as above this temperature, the iron electrode oxidizes quickly. The thermal electromotive force of this thermocouple is rather high. This thermocouple is used for heat treating operations of light non-ferrous alloys.

Chromel vs alumel thermocouple is used for measurement of temperature up to 1100°C and at present time finds a widespread application in industry.

Thermal electromotive force of this thermocouple is quite high. The chemical composition of alumel: nickel 94 per cent; aluminum 2 per cent, silicon 1 per cent; iron 0.5 per cent; manganese 2.5 per cent. The chemical composition of chromel: nickel 89 per cent; chromium 9.8 per cent; iron 1.0 per cent and manganese 0.2 per cent.

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Nickel vs nichrome thermocouple is applied for measurement of temperature up to 900°C . It possesses good thermoelectrical properties, that permits to use this thermocouple on a widescale. The deficiency of this thermocouple is an increasing, with the time, brittleness of the nickel conductor, due to recrystallization of nickel at temperatures of $700-800^{\circ}\text{C}$.

2. Measurement of Temperature with Thermocouples

The measurement of temperature with the aid of a thermocouple consists, as it was said, of measuring of the thermal electromotive force developed at heating of conductors junction with galvanometer. Taking the reading of the thermal electromotive force from galvanometer and using the curve of the thermocouple graduation, the temperature can be determined.

The modern galvanometers have two scales: one of them shows the thermal electromotive force in millivolts, another - the temperature in degrees. Some galvanometers have only the temperature scale.

The reading of the galvanometer is always less than the actual thermal electromotive force, since a part of it is spent on overcoming the ohmic resistance of the thermocouple and connecting wires. The error in readings would be the lesser, the lower is the resistance of galvanometer in comparison with the resistance of the whole circuit. In order to reduce the error, the outside resistance, equal to 15 ohms, is connected to galvanometer's terminals.

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3. The Basic Errors Made at Measurement of Temperature with Thermocouples.

The following factors influence appreciably the results of temperature determination with the aid of thermocouples .

1. Flightiness of cold junction temperature. Therefore, it is necessary to take care , during operation , that the cold ends of the thermocouple and galvanometer would not be heated by the source of heat /furnace/ . .

2. Utilization of galvanometers with different scales / or thermocouples of different graduation /. That is why it is necessary to check , during operation , the correspondence of the type of thermocouple and galvanometer.

3. Utilization of thermocouple , beyond the limits of temperature interval , recommended for its application. The unnecessary high heating of the material of some conductors leads not only to the shortening of the service time of the thermocouple , but causes also the change in its graduation. That is why , the measurement of temperature with a thermocouple should be carried out only within those limits , which are recommended for this purpose.

4. Incorrect setting of the thermocouple in the furnace . If the thermocouple has been set incorrectly in the furnace , a distortion of the results of the temperature measurement may take place . Thus , for example , if the thermocouple is placed near the heating elements, it records an increased temperature , since its hot junction, in this case , is heated more intensively.

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It is necessary to remember , that at heating or cooling of the furnace , the thermocouple shows the temperature with some delay. The faster the rate of heating or cooling and the higher the thermal inertia of the thermocouple , the greater would be the error. If the thermocouple is placed in direct vicinity of the cold articles subjected to heating , than it would show lowered temperature up to the moment, when the temperature of the articles equalizes with the temperature of the surrounding medium .

5. An entanglement of conductors at their joining at the time of repair. In this case , parasitic thermocouples may form , which can cause quite appreciable distortion in the temperature measurement.

6. The errors of the device / galvanometer/. These errors appear as a result of rubbing off of separate sections of the scale , and because of unilateral excessive heating of the instrument.

7. Errors due to inaccuracy of the thermocouple / for example damage of conductor's insulation /.

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Chapter XI

EQUIPMENT USED FOR HEAT TREATMENT AT MILITARY CONDITIONS

At military conditions , the following equipment is used for heat treatment of aircraft parts :

1. Furnace M⁷-2.
2. Lamp A⁷ and torch lamp
3. Devices and tools.

1. Furnace M⁷-2.

At military conditions the electric muffle furnace / Fig. 51/ may be used for heat treatment of small parts / bolts , pins/ and tools. It consists of a body and a stand. Inside of the furnace's body , a heating element is installed which is wound with a heating wire of alloy No.2B. The space between the furnace shell and the muffle is filled with a heat isolating material . Dimensions of the furnace working space are as follows : height 95 mm, width 175 mm., length 300 mm.

The furnace is designed for working temperature of 1000°C and current tension 220 volts . It is provided with a thermoregulator , which automatically maintains the predetermined temperature in the furnace.

The automatic temperature regulation is maintained within the limits from 500 to 1000°C with the accuracy of $\pm 15^{\circ}\text{C}$.

For control of the furnace temperature , a discindicator 1, with a scale in degrees Centigrade from 500 to 1000°C through each 100°C, is fastened to the furnace front wall.

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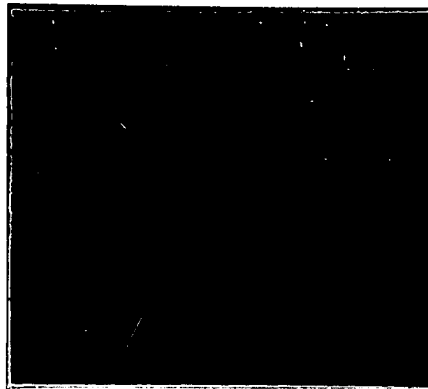


Fig.51. Furnace II -2

1. disc-indicator ; 2 - lamp.

To switch the furnace into an electric current main, it is necessary to lead the tension to the delivery contacts , mounted on the back wall of the furnace. At this, the left lamp 2, set on the furnace front wall , will light up. After this the disc-indicator handle 1 is to be set on a temperature 100°C the predetermined.

If it is necessary to heat the furnace up to 1000°C , then in this case , the handle is set against division 1000°C . At first making of thermoregulator, the handle is to be set on the predetermined temperature , after which the predetermined temperature will be maintained in the furnace automatically.

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The correctness of thermoregulators operation is checked with a standard thermocouple and galvanometer. If the thermoregulator shows the temperature incorrectly, then it is necessary to regulate it according to the instruction furnished by the furnace supplier.

2. Lamp A-70 and Torch Lamp

Lamp A-70 and torch lamp are the most accessible source of heating and can be used for heat treatment of duralumin blanks, intended for the manufacture of aircraft parts.

Temperature control at heating with Lamp A-70 or torch lamp can be accomplished with thermocouple and galvanometer or other thermal-metric devices. Besides that, by utilizing lamp A-70 or torch lamp it is impossible to create if any extensive holding at definite temperature required, for example, for annealing of duralumin. Therefore, the usage of these lamps is limited to such heat treatment, where extensive holding at definite temperature is unnecessary, for instance, for temporary destrengthening of hardened and aged duralumin grades D16T and D17, etc.

In the process of heating up to the temperature of 500°C and short holding at this temperature, such duralumin has enough time to restrengthen.

The temperature control at heating of aircraft parts with lamp A-70 and torch lamp is accomplished with the thermalsensitive pencils.

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3. Devices and Tools

Tank for quenching of aircraft parts . The tank for hardening , or as it is usually said , the quenching tank , is made of steel sheets / by welding /. It must be of adequate dimensions , in order that the cooling medium / water or oil / in the tank is slightly heated from the quenching parts .

For exemplary calculation of the cooling liquid in the quenching tank, it may be proceeded from the fact that for 1 kg of quenching parts 5-6 litres of water or 11-12 litres of oil are necessary. If the volume of the quenching tank is not large , the cooling medium would be quickly heated up and this may have a negative effect on the quality of hardening .

At military conditions , some other metal vessels may be used for the process of hardening , but on the condition that they would be of an adequate volume for the cooling liquid. It is desirable to provide continuous cooling of the quenching solution.

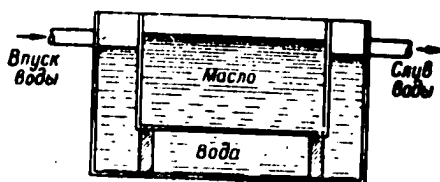


Fig.52. Tank for quenching with double walls:
1/ water inlet , 2/ water outlet , 3/ water, 4/oil. 2074

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For cooling of oil quenching tanks , different cooling devices are applied. One of such simple devices is shown in Fig.52. It consists of an oil tank which is placed into another tank of a larger size , so that a tank with double walls is obtained , with running water circulating between these walls.

For cooling of oil in the quenching tank a coiled pipe with circulating cold water may also be used. The coil is submerged into the oil tank.

When hardening is done in oil , it is necessary to watch the temperature of oil , inasmuch as extensive heating of oil is dangerous and may cause fire . Usually, machine oil is utilized for hardening. Its flash point is in the vicinity of 180-200°C. The oil tanks must be provided with covers in order that in case of inflammation of oil , the tank may be immediately closed.

If hardening is done in water , it is desirable to have a running water. If it is impossible , then the water must be changed as often as possible.

It is very convenient to have a quenching tank equipped with a draw-out net for hardening of small aircraft parts. This releases the operator of the necessity to search the parts , after hardening , on the bottom of the quenching tank.

Tools for heat treatment of aircraft parts

Regular and special tools used for heat treatment of aircraft parts at military conditions are shown in Fig. 53-59.

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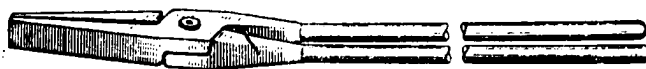


Fig. 53. Tongs with right flat jaws used for a catch of flat aircraft parts .



Fig. 54. Tongs with flat bent jaws used for a catch of round parts and parts with lips.

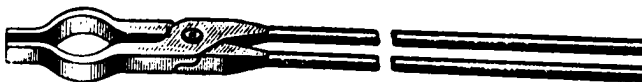


Fig. 55. Tongs with flat convex jaws for a catch of shaped aircraft parts .

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Fig.56. Tongs with shaped flat jaws for a catch of shaped aircraft parts .



Fig.57. Tongs with rounded jaws for a catch of shaped aircraft parts .

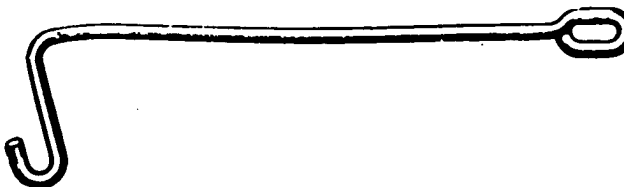


Fig.58. Hook for aircraft parts with holes.

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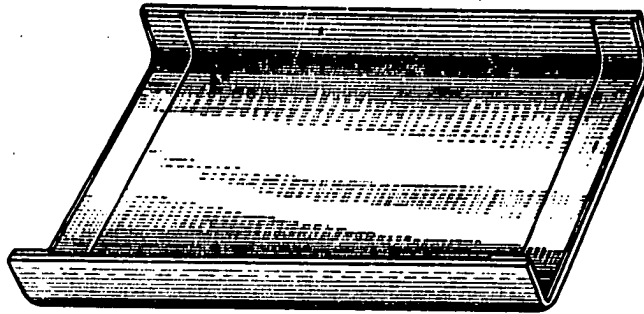


Fig.59. General application tray used for small and medium aircraft parts.

4. The basic rules of safety engineering
at heat treatment of aircraft parts.

In order to avoid traumas during heat treatment of aircraft parts , it is necessary to observe some rules of safety engineering

The basic rules of safety engineering consist in that that it is forbidden to conduct heat treating operations without a preliminary study of equipment , with the aid of which the operations would be performed , and the rules of handling the equipment.

It is necessary to remember always , that the main danger lies not in the furnaces or baths , but in the unskilful and careless handling of equipment.

Besides that , the following rules of safety engineering must be strictly observed.

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1. The premises , in which the heat treating operations are conducted , must have good light / particularly of the working place of the heat treating operator / and ventilation.

2. Equipment , intended for heat treating operations, must be arranged in such a way as to present a free access to the heating furnace and the quenching tank. This is necessary for a quick and unhampered transfer of heated aircraft parts from the furnace into the cooling solution.

3. All the tools / tongs , pliers and others / which the operator uses , must be in a workable condition. It is prohibited to work with unrepaired tools.

4. To protect against burns , the heat treater must operate with working gloves on.

5. When the aircraft parts are submerged into a hot oil bath , it is necessary to watch that the part and the working tool , with which the part is submerged in oil, are completely dry , for when the water gets into a hot oil , it causes strong oil spraying.

6. At the time of charging and discharging of aircraft parts into and out of the electric furnace , the electric current must be switched off in order to protect the workers against electric shocks.

Note. There must be fire extinguishers in workable conditions at the premises , where the heat treatment of aircraft parts is conducted.

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7. When heat treatment of duralumin is performed in an airfield conditions , with utilization of a lamp *АЛЛ* and of a torch flame as the source of heating , it is necessary to choose the place for heat treatment far from the stand of airplanes and the fuel storage , on the territory protected against wind.

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**Table of Conversion of Brinell and Rockwell
Hardness
Number to the Tensile Strength of Steels**

H a r d n e s s						
Brinell Hardness 10/3000	Rockwell Hardness with diamond cone		Rockwell Hard- ness with ball end		Carbon steel	
diameter of inden- tation in mm	Hard- ness num- ber HB	Scale A load P= 60kg	Scale C load P= 150 kg	Scale F, ball load P=60 kg	Scale B ball load P=100 kg	
1	2	3	4	5	6	7
2,34	688	84,5	65,0	-	-	248
2,37	690	85,5	64,0	-	-	241
2,39	659	83,0	63,0	-	-	237
2,42	643	82,5	62,0	-	-	231
2,44	632	-	62,0	-	-	227
2,45	629	82,0	61,0	-	-	226
2,46	621	82,0	61,0	-	-	224
2,47	616	81,5	60,5	-	-	222
2,48	611	-	60,0	-	-	220
2,50	601	81,0	59,0	-	-	216
2,51	597	81,0	59,0	-	-	214
2,52	592	-	59,0	-	-	212
2,53	587	80,5	58,0	-	-	210
2,54	582	80,0	58,0	-	-	208
2,56	578	80,0	57,0	-	-	206
2,57	569	80,0	57,0	-	-	205
2,58	564	79,5	56,5	-	-	203
2,59	560	79,5	56,0	-	-	202

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**Table of Conversion of Brinell and Rockwell
Hardness
Number to the Tensile Strength of Steels**

H a r d n e s s						
Brinell Hardness 10/3000	Rockwell Hardness with diamond cone		Rockwell Hard- ness with ball		Carbon and steel	
diameter of indenta- tion in mm	Hard- ness num- ber HB	Scale A load P= 60kg	Scale C load P= 150 kg	Scale F, ball load P=60 kg	Scale E ball load P=100 kg	
1	2	3	4	5	6	7
2,24	688	84,5	65,0	-	-	248
2,37	670	83,5	64,0	-	-	241
2,39	659	83,0	63,0	-	-	237
2,42	648	82,5	62,0	-	-	231
2,44	638	-	62,0	-	-	227
2,45	627	82,0	61,0	-	-	226
2,46	621	82,0	61,0	-	-	224
2,47	616	81,5	60,5	-	-	222
2,48	611	-	60,0	-	-	220
2,50	601	81,0	59,0	-	-	216
2,51	597	81,0	59,0	-	-	214
2,52	592	-	59,0	-	-	212
2,53	587	80,5	58,0	-	-	210
2,54	582	80,0	58,0	-	-	208
2,56	578	80,0	57,0	-	-	206
2,57	569	80,0	57,0	-	-	205
2,58	564	79,5	56,5	-	-	203
2,59	560	79,5	56,0	-	-	202

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1	2	3	4	5	6	7	8	9	10	11
2,60	555	79,0	56,0	-	-	200	200	189	183	195
2,61	551	79,0	55,0	-	-	198	198	187	182	193
2,62	547	79,0	55,0	-	-	196	197	185	180	191
2,64	538	-	55,0	-	-	194	194	184	178	189
2,65	534	78,5	54,0	-	-	192	192	182	176	187
2,66	530	78,0	54,0	-	-	191	191	180	175	185
2,67	526	-	-	-	-	189	189	179	174	-
2,68	522	78,0	53,0	-	-	187	-	177	-	182
2,70	514	-	-	-	-	185	185	175	170	180
2,71	510	77,5	52,0	-	-	183	184	173	168	178
2,72	507	77,0	52,0	-	-	182	182	172	167	-
2,73	503	76,5	51,5	-	-	181	181	171	166	-
2,74	499	76,0	51,0	-	-	180	180	170	165	175
2,75	495	76,0	51,0	-	-	178	178	168	163	178
2,76	492	76,0	50,0	-	-	177	177	167	162	-
2,77	488	76,0	50,0	-	-	176	176	166	161	-
2,78	485	76,0	50,0	-	-	175	175	165	160	172
2,79	481	-	50,0	-	-	173	-	163	-	168
2,81	474	76,0	49,0	-	-	171	171	161	156	-
2,82	470	76,0	49,0	-	-	169	169	160	155	165
2,83	467	75,0	48,5	-	-	168	168	159	154	-
2,84	464	75,0	48,0	-	-	167	167	158	153	163
2,85	461	75,0	48,0	-	-	165	166	156	152	-
2,86	457	75,0	48,0	-	-	164	164	155	151	-
2,87	454	75,0	48,0	-	-	163	163	154	150	160
2,88	451	74,5	47,5	-	-	162	162	153	149	158

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	2	3	4	5	6	7	8	9	10	11
2,89	448	74,0	47,0	-	-	161	161	152	148	-
2,90	444	74,0	47,0	-	-	160	160	151	146	156
2,91	441	74,0	46,0	-	-	159	159	150	145	154
2,92	438	73,5	46,0	-	-	158	158	149	144	-
2,93	435	73,0	46,0	-	-	156	156	148	143	-
2,94	432	73,0	45,0	-	-	155	155	147	142	-
2,95	429	73,0	45,0	-	-	154	154	146	141	150
2,96	426	73,0	45,0	-	-	153	153	145	140	-
2,97	423	73,0	44,5	-	-	152	152	144	139	-
2,98	420	73,0	44,0	-	-	151	151	143	138	147
2,99	417	73,0	44,0	-	-	150	150	142	137	-
3,00	415	73,0	44,0	-	-	149	149	141	137	145
3,01	412	72,5	43,5	-	-	148	148	140	136	-
3,02	409	72,0	43,0	-	-	147	147	139	135	143
3,04	404	72,0	43,0	-	-	145	-	137,5	-	141
3,05	401	72,0	43,0	-	-	144	144	136	132	-
3,06	398	72,0	42,0	-	-	143	143	135	131	139
3,07	395	72,0	42,0	-	-	142	142	134	130	-
3,08	393	72,0	42,0	-	-	141	141	134	130	137
3,09	390	71,5	41,5	-	-	140	140	132	129	-
3,10	388	71,0	41,0	-	-	139,5	140	132	128	136
3,11	385	71,0	41,0	-	-	138	138	131	127	-
3,12	383	71,0	41,0	-	-	138	138	130	126	134
3,13	380	71,0	40,5	-	-	137	137	129	125	-
3,14	378	71,0	40,0	-	-	136	136	128	125	132
3,15	375	71,0	40,0	-	-	135	135	127	124	-

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		2	4	5	6	7	8	9	10	11
0,16	878	70,5	40,0	-	-	134	134	127	123	130
0,17	870	70,0	39,5	-	-	133	133	126	122	-
0,18	868	70,0	39,0	-	-	132	-	125	-	128,5
0,20	863	70,0	39,0	-	-	131	131	123,5	120	127
0,21	861	70,0	39,0	-	-	130	130	123	119	-
0,22	359	70,0	39,0	-	-	129	126	122	118	125,5
3,23	356	69,5	38,5	-	-	128	124	121	117	-
3,24	354	69,0	38,0	-	-	127,5	124	120,5	117	124
3,25	352	69,0	38,0	-	-	127	123	120	116	-
3,26	350	69,0	38,0	-	-	126	122	119	115	122,5
3,27	347	69,0	38,0	-	-	125	121	118	114	-
3,28	345	69,0	37,5	-	-	124	121	117	114	121
3,29	343	69,0	37,0	-	-	123	120	116	113	-
3,30	341	69,0	37,0	-	-	122,5	119	116	112	119
3,31	339	69,0	37,0	-	-	122	119	115	112	-
3,32	337	68,5	36,5	-	-	121	118	114,5	111	118
3,33	335	68,0	36,0	-	-	120	117	114	110	-
3,34	333	68,0	36,0	-	-	120	-	113,5	-	117
3,35	331	68,0	36,0	-	-	119	115	112	109	-
3,36	329	68,0	36,0	-	-	118	115	112	108	115,5
3,38	325	68,0	35,0	-	-	117	114	110	107	114
3,39	323	68,0	35,0	-	-	116	113	110	106	-
3,40	321	68,0	35,0	-	-	115,5	112	109	106	112
3,41	319	68,0	35,0	-	-	115,0	111	108	105	-
3,42	317	67,5	34,5	-	-	114	111	108	104	111
3,43	315	67,0	34,0	-	-	113	110	107	104	-
3,44	313	67,0	34,0	-	-	112,5	-	106,5	-	109,5

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1	2	3	4	5	6	7	8	9	10	11
3,45	311	67,0	84,0	-	-	112	109	108	102	-
3,46	309	67,0	83,5	-	-	111	108	105	102	108
3,47	307	67,0	82,0	-	-	110	107	104	101	-
3,48	306	67,0	82,0	-	-	110	-	104	-	107
3,50	302	67,0	82,0	-	-	108,5	106	102,5	100	105,5
3,51	300	67,0	82,0	-	-	108	105	102	99	-
3,52	298	67,0	82,0	-	-	107	104	101,5	98	104
3,53	297	66,5	82,0	-	-	107	104	101	98	-
3,54	295	66,0	81,5	-	-	106	103	100,5	97	103
3,55	293	66,0	81,0	-	-	105	102	100	97	-
3,56	292	66,0	81,0	-	-	105	102	99,5	96	102
3,57	290	66,0	81,0	-	-	104	101	99	96	-
3,58	288	66,0	81,0	-	-	103,5	-	98	-	101
3,60	285	66,0	80,0	-	-	102,5	100	97	94	100
3,61	282	66,0	80,0	-	-	102	99	96	93	-
3,62	282	66,0	80,0	-	-	101,5	99	96	93	98,5
3,64	278	-	-	-	-	100	-	94,5	-	97,5
3,65	277	65,0	80,0	-	-	100	97	94	91	-
3,66	275	65,0	80,0	-	-	99	96	93,5	91	96,5
3,67	274	65,0	80,5	-	-	99	96	93	90	-
3,68	272	65,0	80,0	-	-	98	-	92,5	-	95,5
3,70	269	65,0	80,0	-	-	97,5	94	91,5	89	94
3,71	268	65,0	80,0	-	-	96	94	91	88	-
3,72	266	65,0	80,0	-	-	95,5	91	90,5	88	93
3,73	265	64,5	87,5	-	-	95	90	90	87	-
3,74	263	64,0	87,0	-	-	94,5	89	89,5	87	92
3,75	262	64,0	87,0	-	-	94	89	89	86	-
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	1	2	3	4	5	6	7	8	9	10	11
4,05	228	61,0	21,0	-	97,0	80	76	76	74	-	
4,06	222	61,0	21,0	112,0	97,0	80	75	75,5	73	77,5	
4,07	221	61,0	20,5	-	-	80	75	75	72	-	
4,08	219	61,0	20,0	-	-	79	74	74,5	72	76,5	
4,10	217	61,0	20,0	-	97,0	78	74	74	72	76	
4,11	216	61,0	20,0	111,5	96,0	78	73	73	71	-	
4,12	215	61,5	19,5	-	96,0	77,5	73	73	71	75	
4,14	213	-	-	-	-	76,5	-	72,5	-	74,5	
4,15	212	60,0	19,0	-	96,0	76	74	72	70	-	
4,16	211	60,0	19,0	-	-	76	-	72	70	74	
4,17	210	60,0	18,5	111,0	95,0	76	69	71	69	-	
4,18	209	60,0	-	-	95,0	75,5	-	71	-	73	
4,20	207	60,0	18,0	-	95,0	74,5	68	70,5	68	72,5	
4,21	205	60,0	-	110,5	94,0	74	68	70	68	-	
4,22	204	60,0	-	-	94,0	73,5	67	69,5	67	71,5	
4,23	203	59,5	-	-	-	73	67	69	67	-	
4,24	202	59,0	-	-	-	73	67	68,5	67	71	
4,25	201	59,0	-	-	-	72	66	68	66	-	
4,26	200	59,0	-	110,0	93,0	72	66	68	66	70	
4,27	199	58,5	-	-	-	72	66	68	66	-	
4,28	198	-	-	-	-	71,5	-	67,5	-	69,5	
4,30	197	58,0	-	110,0	93,0	71	65	67	65	69	
4,31	196	58,0	-	-	-	71	65	67	65	-	
4,32	195	58,0	-	109,5	92,0	70,5	64	66,5	64	68,5	
4,33	194	58,0	-	-	-	70	64	66	64	-	
4,34	193	58,0	-	-	-	69,5	64	65,5	64	67,5	
4,35	192	58,0	-	-	-	69	63	65	63	-	
4,36	191	58,0	-	-	-	69	63	65	63	67	

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	1	2	3	4	5	6	7	8	9	10	11
4,05	228	61,0	21,0	-	97,0	80	76	76	74	-	-
4,06	222	61,0	21,0	112,0	97,0	80	75	75,5	73	77,5	-
4,07	221	61,0	20,5	-	-	80	75	75	72	-	-
4,08	219	61,0	20,0	-	-	79	74	74,5	72	76,5	-
4,10	217	61,0	20,0	-	97,0	78	74	74	72	76	-
4,11	216	61,0	20,0	111,5	96,0	78	73	73	71	-	-
4,12	215	61,5	19,5	-	96,0	77,5	73	73	71	75	-
4,14	213	-	-	-	-	76,5	-	72,5	-	74,5	-
4,15	212	60,0	19,0	-	96,0	76	74	72	70	-	-
4,16	211	60,0	19,0	-	-	76	-	72	70	74	-
4,17	210	60,0	18,5	111,0	95,0	76	69	71	69	-	-
4,18	209	60,0	-	-	95,0	75,5	-	71	-	73	-
4,20	207	60,0	18,0	-	95,0	74,5	68	70,5	68	72,5	-
4,21	205	60,0	-	110,5	94,0	74	68	70	68	-	-
4,22	204	60,0	-	-	94,0	73,5	67	69,5	67	71,5	-
4,23	203	59,5	-	-	-	73	67	69	67	-	-
4,24	202	59,0	-	-	-	73	67	68,5	67	71	-
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4,33	194	58,0	-	-	-	70	64	66	64	-	-
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4,35	192	58,0	-	-	-	69	63	65	63	-	-
4,36	191	58,0	-	-	-	69	63	65	63	67	-

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4,10	217	61,0	20,0	-	97,0	78	74	74	72	76	
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4,16	211	60,0	19,0	-	-	76	-	72	70	74	
4,17	210	60,0	18,5	111,0	95,0	76	69	71	69	-	
4,18	209	60,0	-	-	95,0	75,5	-	71	-	73	
4,20	207	60,0	18,0	-	95,0	74,5	68	70,5	68	72,5	
4,21	208	60,0	-	110,5	94,0	74	68	70	68	-	
4,22	204	60,0	-	-	94,0	73,5	67	69,5	67	71,5	
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4,28	198	-	-	-	-	71,5	-	67,5	-	69,5	
4,30	197	58,0	-	110,0	93,0	71	65	67	65	69	
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4,40	187	57,0	-	-	91,0	67,5	62	63,5	62	65	
4,41	186	57,0	-	-	90,0	67	61	63	61	-	
4,42	185	56,5	-	108,5	90,0	67	61	63	61	-	
4,44	184	-	-	-	90,0	66	-	62,5	-	64	
4,45	183	56,0	-	-	89,0	66	60	62	60	-	
4,46	182	46,0	-	-	-	66	60	62	60	-	
4,47	181	56,0	-	-	-	65	60	62	60	-	
4,48	180	56,0	-	-	89,0	65	59	61,5	59	63	
4,49	179	56,0	-	108,0	89,0	64	59	61	59	-	
4,51	178	56,0	-	-	-	64	59	61	59	-	
4,52	177	56,0	-	-	88,0	63,5	58	60	58	62	
4,53	176	-	-	107,5	88,0	-	-	-	-	-	
4,55	174	55,0	-	-	87,0	62,5	57	59	57	61	
4,57	173	55,0	-	-	-	62	57	59	57	-	
4,58	172	-	-	107,0	87,0	-	-	-	-	-	
4,60	170	55,0	-	-	86,0	61	56	58	56	59,5	
4,62	169	55,0	-	106,0	86,0	61	56	57	56	-	
4,63	168	54,5	-	-	-	61	55	57	55	-	
4,65	167	54,0	-	-	85,0	60	55	57	55	58,5	
4,66	166	54,0	-	-	-	60	55	56	55	-	
4,67	165	53,5	-	105,5	85,0	59	54	56	54	-	
4,68	164	-	-	-	85,0	59	-	56	-	57,5	
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4,82	154	52,0	-	-	-	55	51	52	51	-
4,84	153	-	-	103,5	81,0	55	-	52	-	53,5
4,85	152	52,0	-	-	81,0	55	50	52	50	-
4,87	151	51,5	-	-	-	54	50	51	50	-
4,88	150	51,0	-	103,0	80,0	54	50	51	50	52,5
4,90	149	51,0	-	-	80,0	54	49	51	49	-
4,91	148	51,0	-	-	79,0	53	49	50,5	49	51,5
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4,95	146	50,0	-	-	78	53	48	50	48	-
4,96	145	50,0	-	-	78	52	48	49,5	48	50,5
4,97	144	50,0	-	101,5	78	52	48	49	48	-
5,00	143	50,0	-	-	77	51	47	48,5	47	49,5
5,02	141	-	-	101,0	77	-	-	-	-	-
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5,06	139	-	-	100,5	76	-	-	-	-	-
5,08	138	-	-	-	76	50	-	47	-	48,5
5,10	137	-	-	100,0	75	49	45	47	45	-
5,12	135	-	-	99,5	74	49	-	46	-	47,5
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5,16	133	-	-	-	73	48	-	45,5	-	46,5
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	1	2	3	4	5	6	7	8	9	10	11
5,21 120	-	-	98,5	72	-	-	-	-	-	-	-
5,23 129	-	-	-	-	46,5	-	44	-	45	-	-
5,25 128	-	-	-	71	46	42	44	42	-	-	-
5,27 127	-	-	98,0	71	46	-	48	-	44,5	-	-
5,30 126	-	-	-	70	45	42	43	42	-	-	-
5,31 125	-	-	97,5	70	45	-	42,5	-	43,5	-	-
5,33 123	-	-	97,0	69	44	41	42	41	43	-	-
5,40 121	-	-	96	68	42,5	40	41	40	42,5	-	-
5,44 119	-	-	95,5	67	42	-	40,5	-	42	-	-
5,45 118	-	-	-	67	42	39	40	39	-	-	-
5,48 117	-	-	95,0	66	42	39	39,5	39	41	-	-
5,50 116	-	-	94,5	65	42	38	39	38	-	-	-
4,52 115	-	-	-	65	41,5	-	39	-	40,5	-	-
5,55 114	-	-	94,0	64	41	38	39	38	-	-	-
5,57 113	-	-	-	64	41	-	38,5	-	40	-	-
5,59 112	-	-	92,5	63	40	37	38	37	-	-	-
5,61 111	-	-	-	63	40	37	38	37	39	-	-
5,63 110	-	-	92,0	62	39,5	-	-	-	-	-	-
5,65 109	-	-	-	61	39	36	37	36	-	-	-
5,68 108	-	-	92,5	61	39	-	-	-	-	-	-
5,70 107	-	-	92,0	59	39	35	36	35	-	-	-
5,73 106	-	-	91,0	59	38	-	-	-	-	-	-
5,76 105	-	-	-	58	38	35	36	35	-	-	-
5,78 104	-	-	90,5	58	-	-	-	-	-	-	-
5,80 103	-	-	90,0	57	37	34	35	34	-	-	-
5,83 102	-	-	-	56	37	-	-	-	-	-	-
5,85 101	-	-	89,5	56	37	34	35	34	-	-	-
5,87 100	-	-	89,0	55	36	33	34	33	-	-	-

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	1	2	3	4	5	6	7	8	9	10	11
8,90 99	-	-	-	-	54	36	33	34	33	-	-
8,98 98	-	-	-	88,5	54	35	-	-	-	-	-
8,96 97	-	-	-	88,0	53	35	32	33	32	-	-
8,99 96	-	-	-	87,0	52	34,5	-	-	-	-	-
8,04 94	-	-	-	-	51	34	-	-	-	-	-
8,10 92	-	-	-	85,5	49	33	-	-	-	-	-
8,16 90	-	-	-	85,0	48	32,5	-	-	-	-	-
8,22 88	-	-	-	84,5	47	32	-	-	-	-	-
8,28 86	-	-	-	83,5	45	31	-	-	-	-	-
8,35 84	-	-	-	-	43	30	-	-	-	-	-
8,42 82	-	-	-	82,0	42	29,5	-	-	-	-	-
8,48 80	-	-	-	81,0	40	29	-	-	-	-	-
8,56 78	-	-	-	79,5	38	28	-	-	-	-	-
8,63 76	-	-	-	78,5	36	27,5	-	-	-	-	-

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